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Rotating Binding to Snowboard Interface

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Rotating Binding to Snowboard Interface

A Major Qualifying Project Report

Submitted to the Faculty

Of the

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science

In Mechanical Engineering

By:

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0. Abstract

The objective of this project was to design, build, and test a rotating binding-to-snowboard interface that allows the user to rotate their front foot in small increments hands free and provide riders with increased comfort and safety. Currently, there are no devices on the market that allow the user to do so without the use of a release mechanism or tools. The system uses a pre-made ball plunger as a follower and a circular cam to allow the rider to rotate the binding on demand while also preventing unwanted rotation during normal riding conditions. The prototype will be bench tested to measure the torque required to rotate the device. The device will also be tested on slope to ensure functionality while entering and exiting the ski lift as well as riding down the mountain.

1. Introduction

1.1. Objective

To design, build, and test a binding-to-snowboard interface which allows the angle of adjustment to be adjusted in small increments without the use of hands or tools, but will also withstand the max loads produced under extreme riding conditions. The interface is to be under four pounds and no thicker than 1.5”.

1.2. Rationale

Different foot positions put strain on different parts of the body. Allowing the rider to adjust the angle of adjustment will permit the user to ride more comfortably and efficiently. This design also allows the user to adjust the angle of adjustment at a moment's notice; without it some disassembly and tools may be required. Besides comfort and convenience, this design may also reduce the chance of injury to the ankle and knee with one foot strapped in.

1.2.1. Safety Research

The injury rate was found to be 6.05 injuries per 1000 skier days, while 27.3 % of those injuries occurred while snowboarding (Greece, 2007). The U.S. Consumer Product Safety Commission estimates that 37,600 snowboarding injuries were treated in the nation's emergency rooms in 1997. 19.8% (7445) of those injuries were lift-related (Children's Hospital of Pittsburgh, 2008). By allowing the rider's foot to rotate 360 degrees when a high rotational load is applied it may prevent some lift related injuries.

1.2.2. Market Research

In 2000, 25.9 % of all ski area visits (51.6-million) were snowboarders, making a total of 13.36-million (Transworld, 2001). In the U.S. in 2008, there were 5.1-million snowboarders. This number is slowly declining due to worsening weather conditions (like less snow), returns to skiing, and crowded resorts (Planet Green, 2008). Overall, the snow sports market sales declined 5% in dollars and 3% in units for the 2008-09 season. This season brought a total of \$2.82 billion compared to last season's \$2.95 billion in sales. Current season equipment took the heaviest blow, with 75,000 fewer alpine skis, 8,000 fewer Nordic skis, and 34,000 fewer snowboards sold than last season. Equipment from the previous season sold well as retailers discounted prices and cut margins to the bone to bring in customers and move inventories (First Tracks Online, 2009). Although the numbers for both snowboarders and snowboard sales are declining, there is still a large market for such a product.

1.3. State of the Art

Using search engines Google and PatentStorm.us, a thorough literature search was conducted. The results of the literature research were sparse in finding a rotatable snowboard binding or interface that didn't require a release mechanism and allowed many rotational positions for the binding adjustment. However, through this research, many rotatable snowboard bindings and interfaces were found that are being manufactured and sold on the current market. The most interesting design currently on the market that achieves many different rotational positions is named the "Swivler" (www.swivler.com). The Swivler allows rotation of the binding every 30° until it completes a 180° rotation, but requires a mechanical release before any rotation can occur. US Patent Number 6575489 describes the Swivler device in complete detail.

The Swivler is made of a variety of lightweight polymers and is simple for any user to operate. This device allows rotation of the binding, but it also only allows a limited amount of rotational positions and requires the use of a hand release. This is a mechanism that allows it to rotate to any of its limited positions. The device does allow more comfort to riders while waiting in the lift lines, but still remains in a locked position until the release mechanism is engaged. This limitation of only allowing rotation when the release mechanism is engaged provides no benefit in reducing injurious loads while entering and exiting the chair lift.

A comparable product to the Swilver is manufactured by Sports180, Inc and their product is named the “Flip-U” (www.sports180.com). US Patent Number 6923454 describes the Flip-U device in full detail. The Flip-U is a lightweight design that allows rotation every 90° until it completes a 180° rotation. The device also requires the use of a release mechanism to permit any rotation, similar to the Swivler design. This device has no benefits of preventing lift injuries because of its dependence on a release mechanism as well. The creation of a binding interface that allows rotation on demand without the use of a release mechanism would allow the comfort and convenience of the devices on the market, and at the same time reduce the chance of injury while entering and exiting the lift. A new device would need to allow a complete 360° rotation to prevent such injuries from occurring during the event of a lift related accident. Such a device was achieved by students attending Worcester Polytechnic Institute in 2007 (Adamson, et al., 2007) and 2009 (Hill, et al., 2009). These two different groups of individuals were able to create a design that allowed hands-free rotation, but neither design allows the convenience of offering a variety of rotational positions for the user.

Even with all these designs currently on the market, there is still a need for a hands-free rotatable snowboard binding. With the addition of multiple rotational positions along a 360⁰ rotational range, an increased customer demographic could be achieved.

1.4. Approach

With the use of axiomatic design a lighter, thinner, and ergonomic design was achieved. This design will allow the user to personalize the angle of adjustment without the hassle of using their hands. Some state-of-the-art designs require the user to pull a release lever to allow the binding to rotate; our intention is to create a design which allows the user to simply apply a rotational load in order to change the angle of adjustment. The developed design will allow greater comfort and ease on entering and exiting the ski lift, while withstanding loads experienced during normal riding conditions.

SolidWorks, computer aided design software, was used to model our design. Before machining of the prototype could begin, ANSYS, a finite element analysis (FEA) software, was used to check for any possible mechanical failures that could occur during use. Following the completion of the SolidWorks models and FEA analysis, the design was imported into the computer aided machining software, ESPRIT. The ESPRIT software allowed us to design the tool paths required to accurately machine the parts of our prototype. With the ESPRIT programming completed, the parts were then machined using the Haas MiniMills and VF4. The Delrin™ parts of the prototype were also modeled using SolidWorks, but some parts were imported into the computer aided design software AutoCAD in order to create two dimensional drawings. The two dimensional drawings were then uploaded to a Universal Laser Systems VLS4.60 60W laser cutter in order to create the top plate and the binding attachment plate.

2. Design Decomposition and Constraints

[FR] Functional Requirements		[DP] Design Parameters	
0	FR Provide an interface between the binding and board which allows	DP	Adjustable rotating binding interface
1	FR Transfer all loads except for rotational from binding to board	DP	Load Transfer system
1.1	FR Transfer loads from Foot to Binding	DP	Binding Straps
1.2	FR Transfer loads from binding to binding attachment plate	DP	Binding attachment plate that is flat against the binding and four mounting bolts 4cm apart in :
1.3	FR Transfer loads from binding to cam	DP	Four mounting bolts 4cm apart in a square pattern that attach from the binding to the cam
1.4	FR Transfer loads from cam to the top plate.	DP	A circular hole in the top plate to the bottom plate with a diameter of 2.85in.
1.5	FR Transfer loads from the top plate to the bottom plate.	DP	Four mounting bolts 4.5in apart in a square pattern along the top plate and the base plate.
1.6	FR Transfer loads from base to snowboard surface.	DP	Bottom plate is flat against the snowboard surface and four mounting bolts 4cm apart in a
2	FR Control Rotation	DP	Cam with a ball plunger system
2.1	FR Prevent rotation at low torques (below $T=15\text{Nm}$)	DP	Ball Plunger positioning in conical detents.
2.2	FR Allow rotation at high torques (above $T=15\text{Nm}$)	DP	Ball plunger and angle of the conical detent . (45 Degrees)
2.3	FR Allow many different angles of adjustment (13)	DP	Multiple conical detents along the outer surface of the CAM. (6.93 degrees apart)
3	FR Prevent Environmental Damage	DP	Top plate and binding attachment plate seal the system from environmental problems.
4	FR Allow Stance Adjustability for any snowboard	DP	Use currently practiced methods and apply it.
4.1	FR Allow placement adjustability	DP	Four mounting holes 4cm apart in a square pattern to allow the binding to be configured for al
4.2	FR Allow the binding angle to be adjustable	DP	Top plate acts as the snowboard surface.

Figure 1: Acclaro Decomposition

2.1.Design Constraints

- The binding-to snowboard interface must allow the angle of the foot to be adjusted in small increments without the use of hands or tools.
- The binding-to-snowboard interface must withstand the maximum loads produced under extreme riding conditions.
- The binding-to-snowboard interface must weigh less than four pounds.
- The binding-to-snowboard interface must be no thicker than 1.5 inches.

2.2.Functional Requirement 0

The first functional requirement, FR0, should clearly state the purpose of the design for any conventional decomposition. This design's purpose is to provide a binding to board interface that will allow hands-free rotation and a variety of positions. To satisfy this functional requirement, DP0, a rotational binding to snowboard interface was created. A three dimensional

model of the binding to snowboard interface can be seen in Figure 2 below. An exploded view of the model with all the DPs labeled can be found in Appendix 11.7.

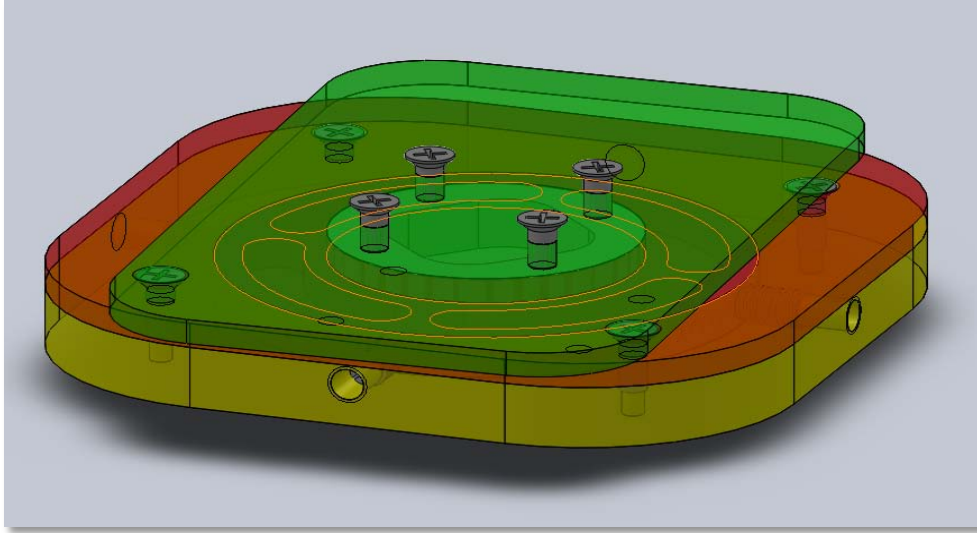


Figure 2: Three-Dimensional Model of Binding to Snowboard Interface

2.3.Functional Requirement 1

To allow the first functional requirement to be completed, loads applied by the rider must be transferred to the snowboard. Without transfer of the loads from the rider to the snowboard, the rider will not be able to edge, jump, or stop successfully. These loads must be transferred from the foot of the rider, between the surfaces of the components of the design, pictured above, to the surface of the snowboard. To ensure the loads are being transferred efficiently, the surfaces of the components must be compatible with one another, the binding's surface, and snowboard's surface. If the components surfaces are not compatible with one another, the binding or the snowboard loads will not be transferred effectively when applied by the rider. Each component of the system is required to efficiently transfer loads from the rider to the snowboard in order to achieve the first functional requirement.

2.3.1. Functional Requirement 1.1

The first transfer of loads in this system is from the rider's foot to a standard commercial binding. The bindings are not part of the designed prototype, but are an essential component in transferring loads from the rider to the snowboard and require analysis.

For this system the conventional "strap-in" bindings were used, which include a strap around the ankle and another over the toes. These two straps can be seen in Figure 3 below. The ankle strap will help keep the rider's foot in position both vertically and horizontally, while the strap over the toes is used to help keep the rider's foot in position to the front and back. The straps can be tightened independently from one another in order to achieve the rider's desired level of comfort. With the ankle and toe strap properly fastened, the rider's foot will be able to apply loads transferrable to the edging surfaces of the snowboard.

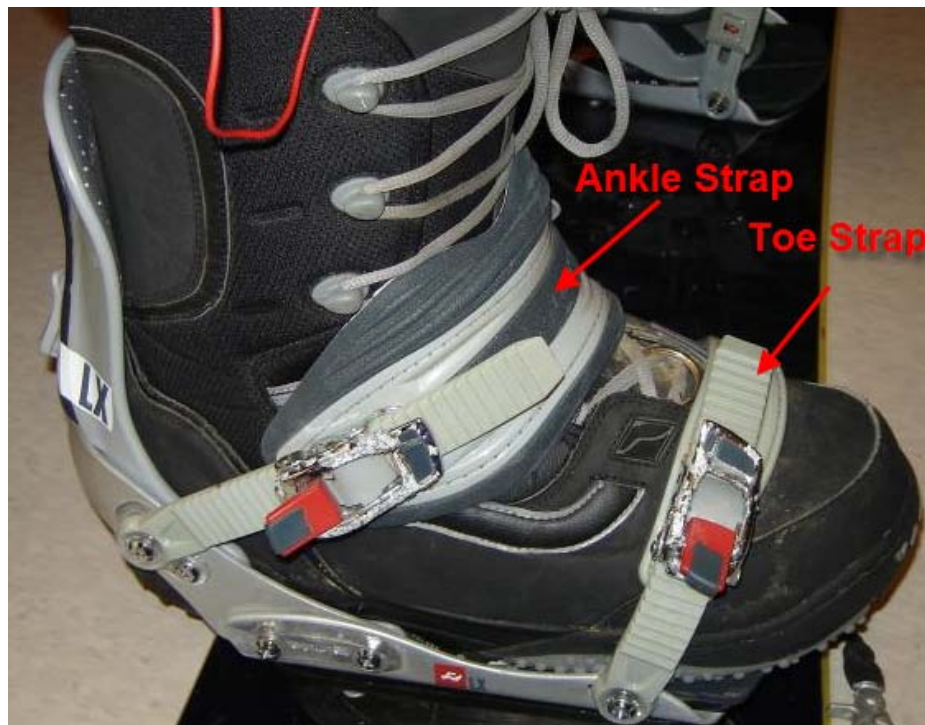


Figure 3: Snowboard "strap-in" bindings.

2.3.2. Functional Requirement 1.2

Once the loads are transferred to the bindings, they must then be transferred into the binding attachment plate of the prototype. The binding attachment plate of the prototype must be able to withstand any moments or torques applied to it from the bindings. To allow the system to experience pitch, roll, and yaw; the binding has to be secured properly to this plate. To achieve this while keeping the surfaces compatible, the industry standard mounting setup must be mimicked on the binding attachment plate. This consists of four holes spaced four centimeters apart in a square pattern. Normally, the mounting bolts are driven from the binding directly into the board and tightened to prevent any vertical separation. This design, however, requires four bolts to be driven from the binding through the binding attachment plate to the cam of the prototype. The four holes that were drilled into the binding plate can be seen in Figure 4 below.

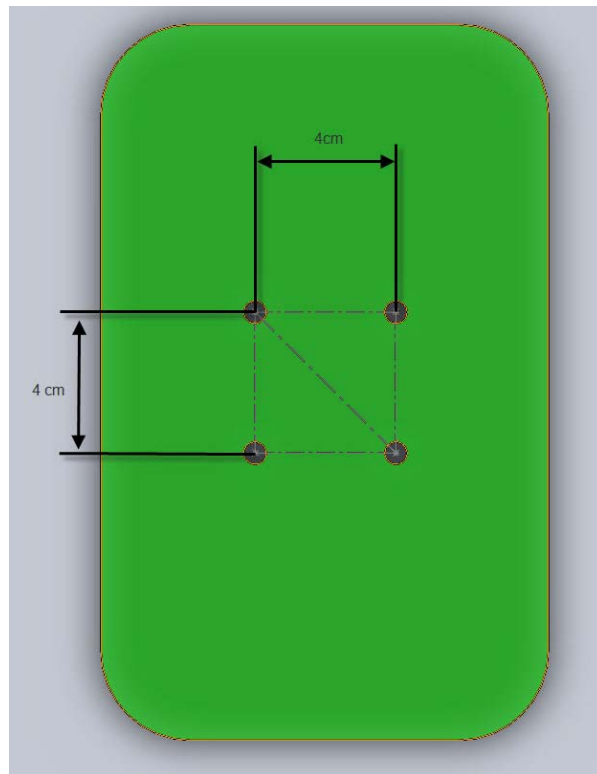


Figure 4: Binding attachment plate, with binding mounting holes shown

2.3.3. Functional Requirement 1.3

Similar to the binding attachment plate, loads must be transferred from the binding to the cam component of the prototype. The cam must withstand any moments or torques applied to it from the bindings. To achieve this while keeping the cam compatible with the binding attachment plate and binding, the industry standard mounting setup must be mimicked on the cam. This again requires four holes four centimeters apart in a square pattern to be drilled into the cam.

The cam was also designed to allow loads applied from the binding to create rotation of the binding attachment plate and binding. The cam is attached securely to the binding by four machine bolts that are also used by the binding attachment plate. The Physical Integration section below provides an analysis of the forces exerted on these machine bolts during the prototype's operation. Figure 5 shows the cam mounted to the binding attachment plate through the use of four machine bolts.

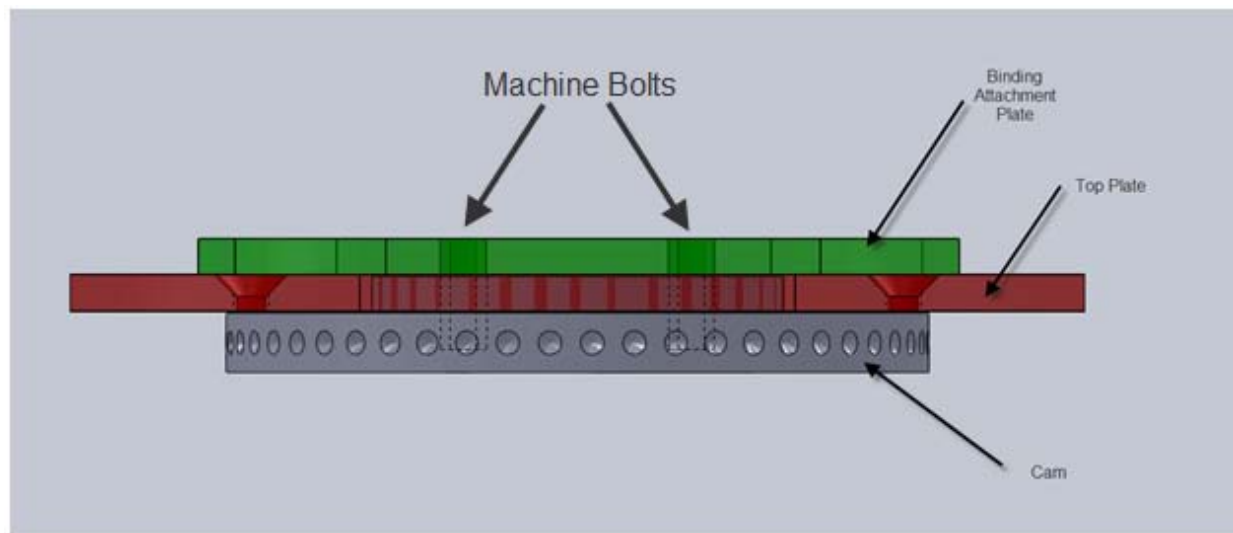


Figure 5: Diagram showing cam mounting bolts through binding attachment plate

2.3.4. Functional Requirement 1.4

To keep the cam securely attached to the rest of the prototype, a top plate component had to be designed. The top plate is sandwiched in between the binding attachment plate and the cam, but allows the cam to make direct contact with the binding plate to allow rotation. To achieve this contact a 2.85 inch hole is created on the top plate that will allow part of the cam to attach to the binding attachment plate but prevent the rest of the cam from moving vertically. Figure 5 above shows the top plate's position between the cam and the binding attachment plate.

The material of the top plate will have to be able to withstand the loads transferred to it by the cam, but also provide surface compatibility to reduce the effects of friction. The Physical Integration section below describes the material analysis of the loads and stresses applied to the top plate. The hole machined in the top plate can be seen in Figure 6 below.

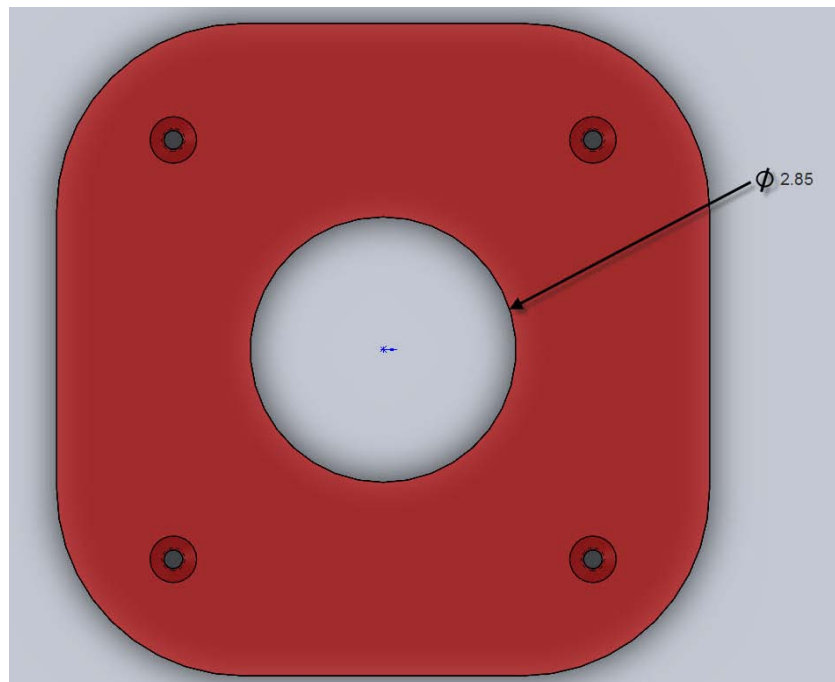


Figure 6: Top plate showing hole for cam

2.3.5. Functional Requirement 1.5

The loads transferred to the top plate need to be transferred to a component attached to the surface of the board. To achieve this, a base plate component of the prototype was designed which attaches directly to the top plate but also contains the bottom portion of the cam. The top plate and base plate have four holes 4.5 inches apart in a square pattern. Machine bolts are driven from the top plate into the base plate. The machine bolts must be able to withstand any of the moments and torques applied during operation of the prototype and normal snowboard riding conditions. The Physical Integration section below describes the analysis done to the four machine bolts. The four holes created in the top plate and base plate can be seen in Figure 7 below.

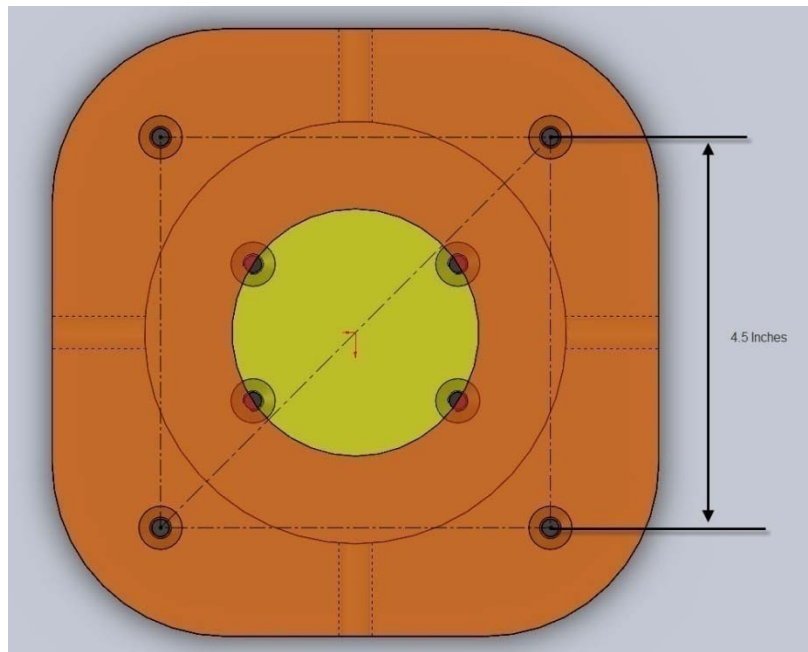


Figure 7: Diagram of Top plate to Base plate attachment bolt pattern

The four holes created on the top plate will differ from those on the base plate by a chamfer; allowing them to lie flush to the top surface of the top plate. These chamfered holes are necessary to prevent the four machine bolts from interfering with the rotation of the binding plate

against the top plate. These holes are chamfered at a 45° conical shape that is parallel with the surface of the machine bolt's heads. These chamfered holes can be seen in Figure 8 below.

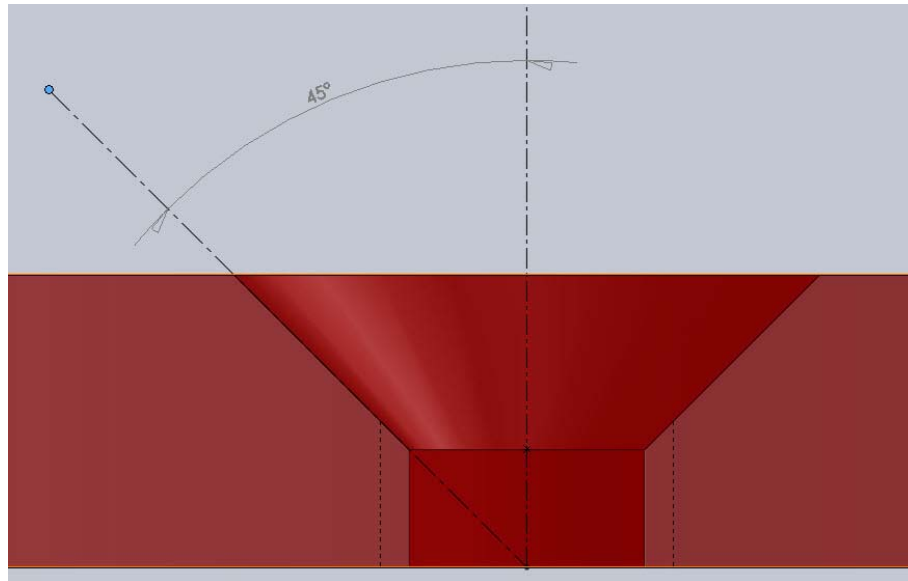


Figure 8: Machine bolt chamfer

2.3.6. Functional Requirement 1.6

The loads transferred to the base plate are required to be transferred directly to the surface of the snowboard. This is achieved by creating a surface that is compatible with the existing snowboard surface. Four holes four centimeters apart in a rectangular pattern are created at the bottom of the base plate pocket. These four holes allow the base plate to align to any four holes four centimeters apart in a rectangular pattern already existing on any snowboard top surface currently on the market. The standard snowboard holes are displayed in Figure 9 below.

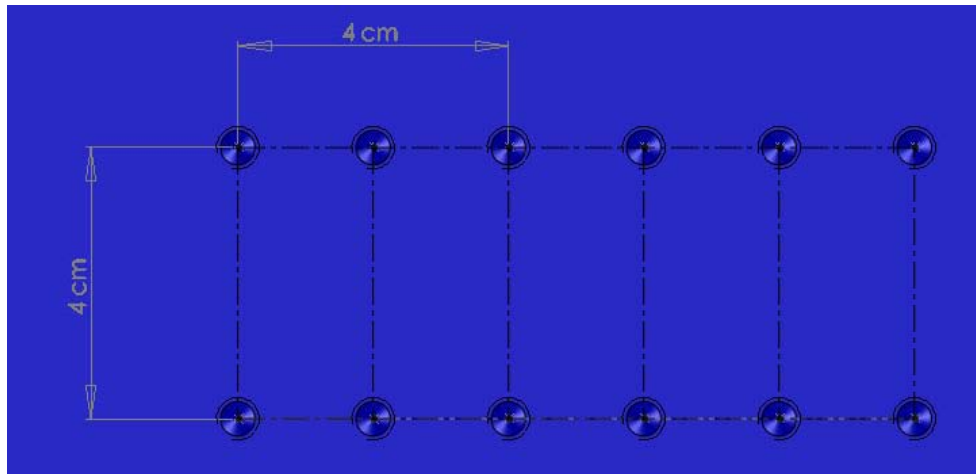


Figure 9: Standard Snowboard mounting hole pattern

Four mounting bolts are then driven from the base plate into the surface of the snowboard. These machine bolts are required to withstand any torques or loads exerted during the operation of the prototype and normal riding conditions. The analysis of these mounting bolts can be seen in the Physical Integration section below.

The four holes in the base plate are chamfered to allow the top of the mounting bolt to be flush with the surface of the pocket in the base plate. This will allow the cam that sits in the base plate to rotate freely without being inhibited by the mounting bolts. These chamfered holes can be seen in Figure 9 above.

2.4.Functional Requirement 2

The second functional requirement was to allow the rider to control the rotation of the interface with their feet. This problem was solved by machining a circular CAM with conical detents along the outer surface and a ball plunger system. This can be seen below in Figure 10.

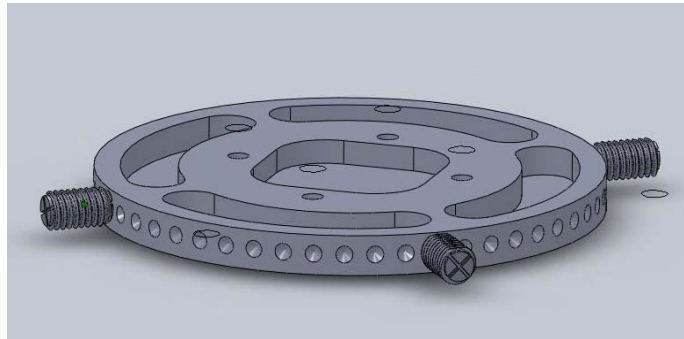


Figure 10: Conical detent and Ball plunger system

2.4.1. Functional Requirement 2.1

Functional Requirement 2.1 is to prevent rotation at low torques. This is considered anything below 15 Nm of torque. Research indicates that this is the maximum rotational force experienced at the base of the boot during normal riding conditions on a snowboard (Knunz, 2001). The way that this was overcome was to drill conical detents into the outer surface of the cam. Four Ball plungers were forced into the detents which require more than 15 Nm of torque to depress. Figure 11 below shows the contact points where the ball plunger is resisted by the detent.

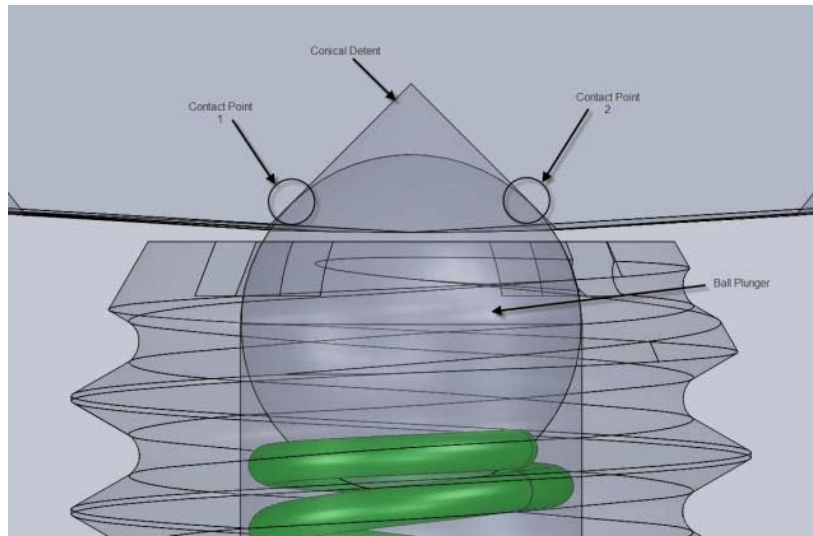


Figure 11: Ball plunger and detent close-up, showing contact points of resistance

2.4.2. Functional Requirement 2.2

For the assembly to function and to decrease the risk of injury, the cam needed to be able to rotate at high torques. When a torque created by the rider either intentionally or unintentionally exceeds 15 Nm, the ball plungers depress and rotate into the next conical detent. In order for this to proceed smoothly, the conical detents need to be aligned and symmetrical as shown in Figure 12 below. This requirement is fulfilled by milling the detents to have 45-degree angled walls and installing the correct ball plungers rated to depress when more than 15 Nm of torque is applied to the cam.

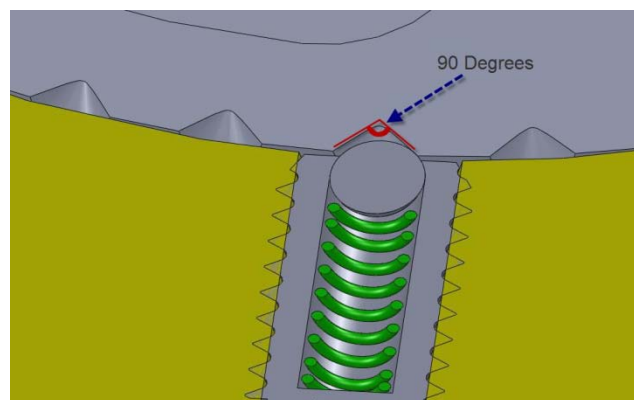


Figure 12: Conical detents, showing the angle of the walls

2.4.3. Functional Requirement 2.3

Functional Requirement 2.3 is to allow for many different angles of adjustment. Previous MQPs have created devices that rotate to either two or four different positions. In order to increase the options that the rider has in terms of control and foot angle, this number needs to be increased. To accomplish this, fifty-two conical detents were drilled along the outer surface of the cam 6.93 degrees apart. Normal rotational use only utilizes a quarter or thirteen detents. To ensure proper placement, they were drilled using an indexer. A diagram of the detent placement can be seen in the Figure 13 below.

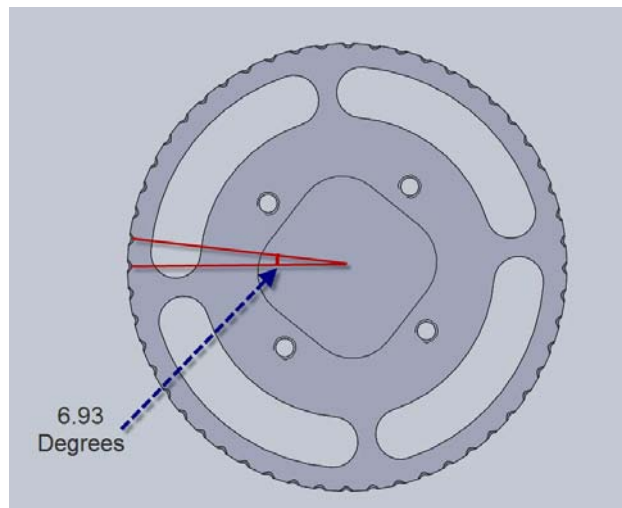


Figure 13: top view of Cam, showing conical detent placement

2.5.Functional Requirement 3

The third Functional Requirement was to prevent environmental damage. Any mechanical system that operates within the elements must be designed to resist or prevent damage from outside factors. Snow and dirt can increase friction between moving parts, decrease lubrication, and cause seizure. In order to solve this problem, a base cover was created that seals the system from the environment. It attaches to the base plate by four threaded machine bolts and seals the cam inside the assembly as shown in Figure 14 below.

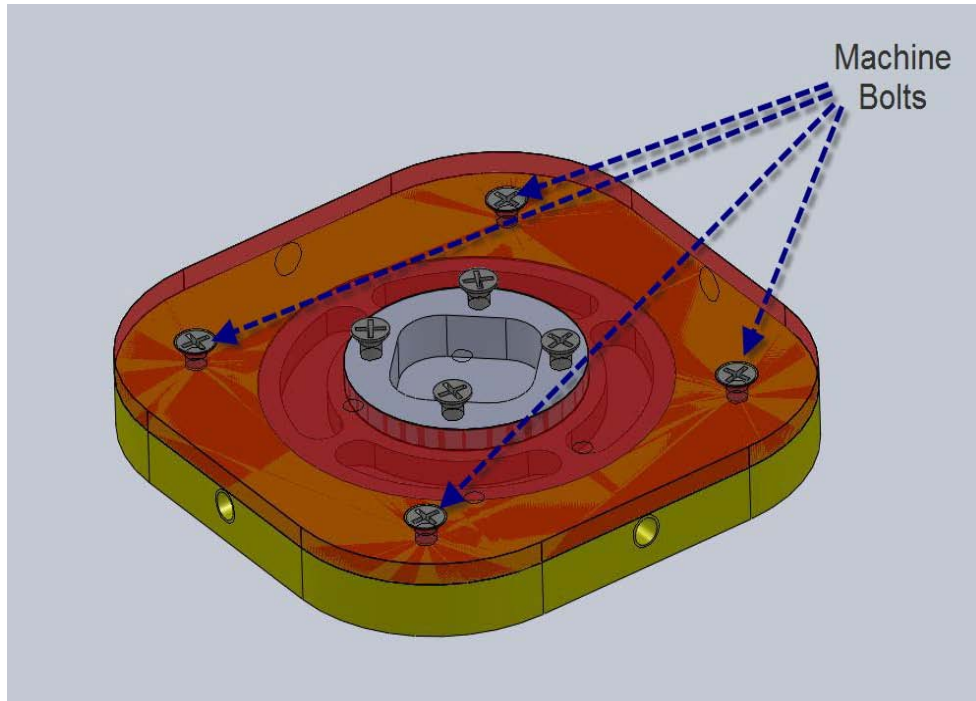


Figure 14: Enclosed assembly machine bolts

2.6.Functional Requirement 4

The fourth Functional Requirement is to allow stance adjustability for any snowboard. When Snowboards are built, they have a standard mounting hole pattern drilled into the top. There are eight holes spaced four centimeters apart for each foot in a pattern similar to that shown below. The snowboard that we tested, however, had a pattern of twelve holes underneath each foot as shown in Figure 15 below. The binding to snowboard interface must be designed to attach to the standard configuration of four centimeters by four centimeters.

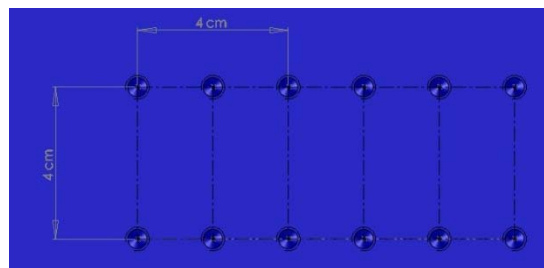


Figure 15: Standard Snowboard mounting hole pattern

2.6.1. Functional Requirement 4.1

Given that the Industry standard is a pattern of eight mounting holes for each foot on the board, the Binding to snowboard interface must have four mounting holes spaced four centimeters apart by four centimeters in a pattern shown below. This is to ensure maximum placement adjustability. In addition, the holes are predrilled using an M6 x 1.0 thread specification. You can see the pattern in the assembly shown here.

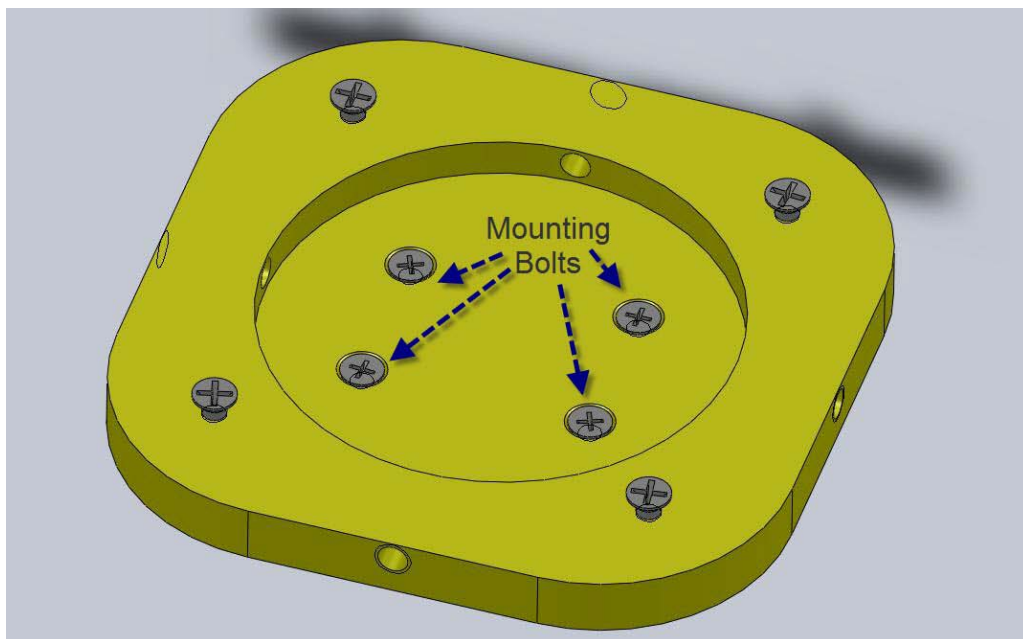


Figure 16: Mounting pattern in the base plate

2.6.2. Functional Requirement 4.2

Functional Requirement 4.2 is to allow the binding to be adjustable. Not every snowboarder rides the same way. Some boarders like their bindings to be in different positions for different conditions on the mountain as well as for different situations. In order for this to be possible, the boarder must be able to adjust the binding as if it were normally connected to the deck of a snowboard. To solve this problem, a quarter-inch thick binding attachment plate is added to the top of the interface to act as the snowboard surface. The binding can now be mounted to this plate and adjusted as the rider sees fit. Figure 17 shows this plate attached to the assembly.

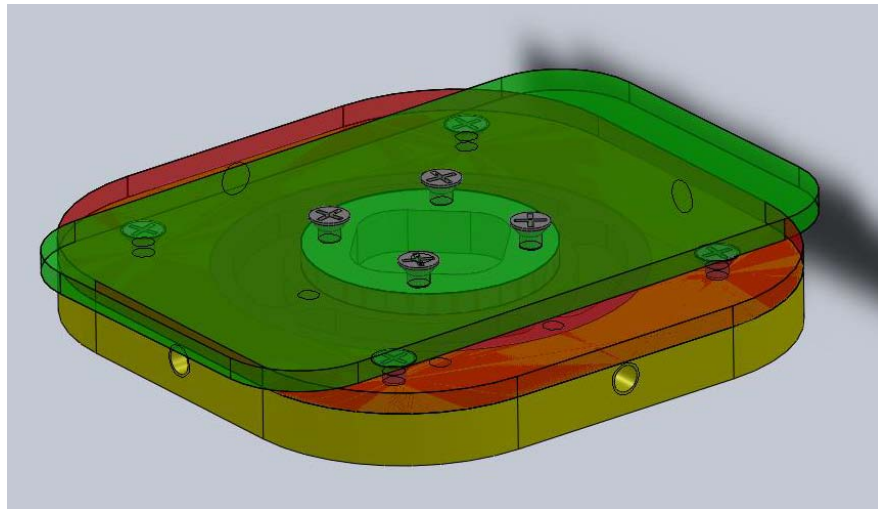


Figure 17: Binding Attachment Plate

3. Physical Integration

3.1. Description of Components

3.1.1. *Bottom Plate*

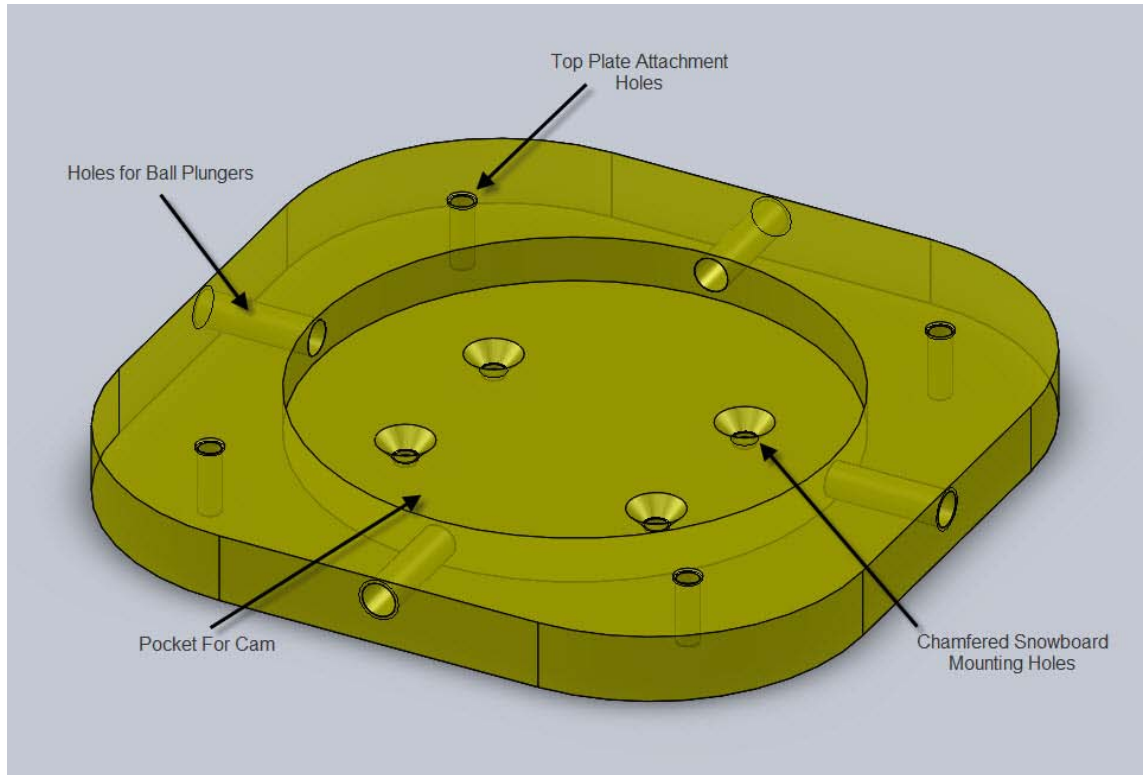


Figure 18: Bottom Plate

The bottom plate's main purpose is to connect the entire device to the snowboard. This component uses four chamfered holes to mount to the standard holes on any snowboard. The main circular pocket houses the cam. The chamfer allows the bolts to sit flush with the bottom surface in order to avoid any interference with the cam. The four holes parallel to the top surface are for the ball plungers. The holes are located, depth-wise, in the center of the cam pocket. The four holes on the top surface of the bottom plate are used to secure the top plate, which can be seen in Figure 21, to the bottom plate. The bottom plate measures 7in x 7in x .625in.

3.1.2. Cam

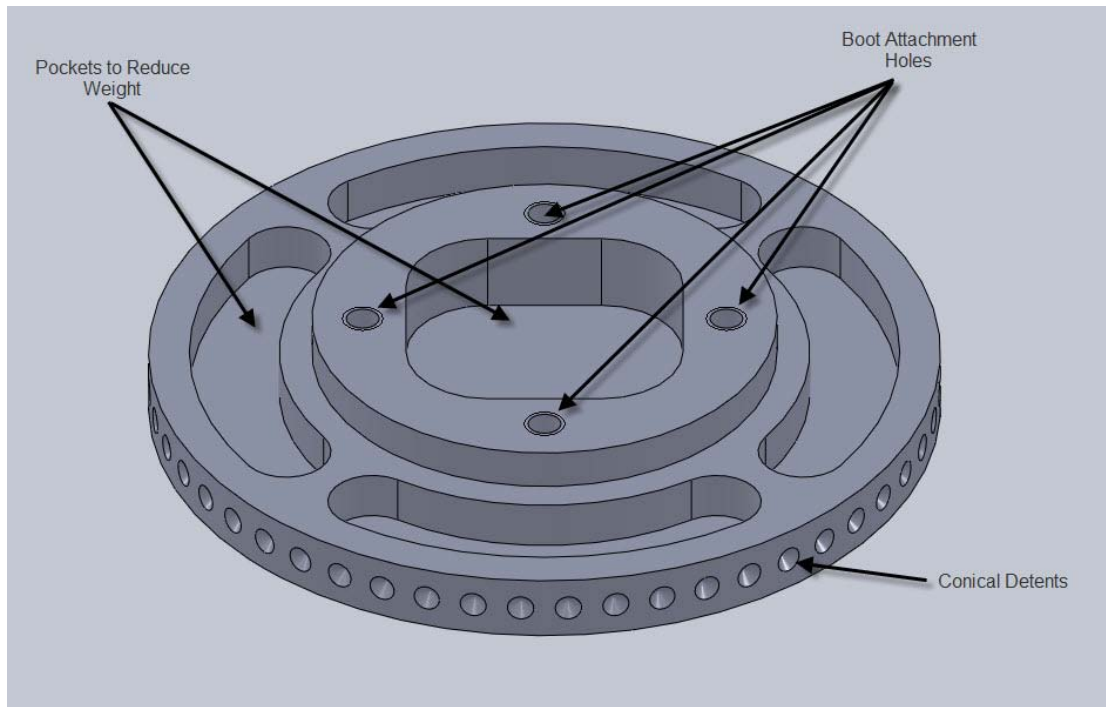


Figure 19: Cam

The cam was designed to act as an interface between the binding and the top and bottom plates, as well as help control the rotation of the binding along with the ball plungers. The cam has a total of 52 positions, of which you would typically use 13, which are designated by the conical detents which can be seen in Figure 20. The cam is round a round shape which allows for easy rotation when the ball plunger is not in a detent. There are several pockets in the cam which reduce the weight of the part without sacrificing too much structural strength. The part is 4.865 inches in diameter and 0.65 inches thick.

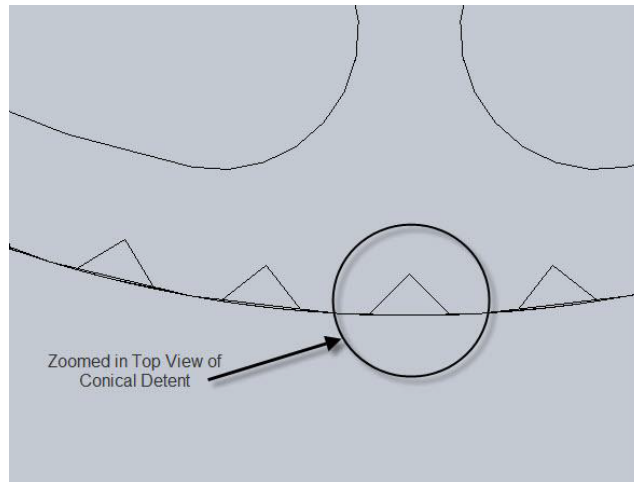


Figure 20: Conical Detent

3.1.3. Top Plate

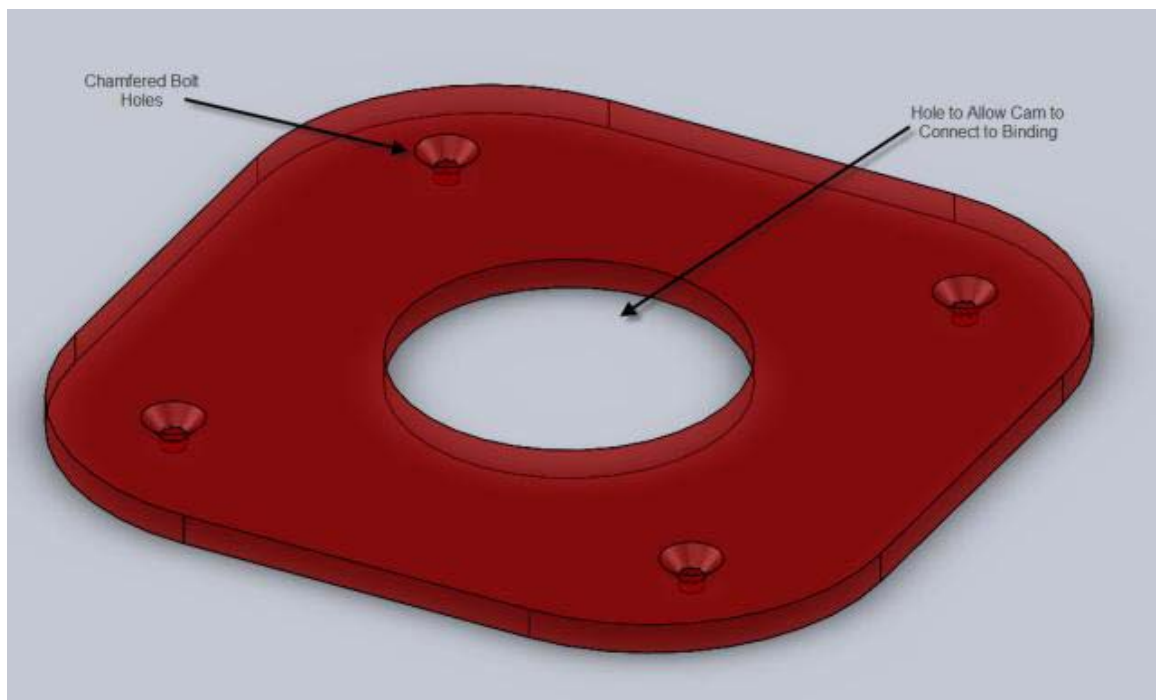


Figure 21: Top Plate

The top plate was designed to hold down the cam by connecting to the bottom plate using the four chamfered bolt holes. The chamfered holes also allow the bolts to sit flush with the top surface in order to avoid any interference with the binding attachment plate during rotation. The

top plate allows the top of the cam to connect to the binding through the hole in the center. The top plate is 7in x 7in x 0.25in in size.

3.1.4. Binding Attachment Plate

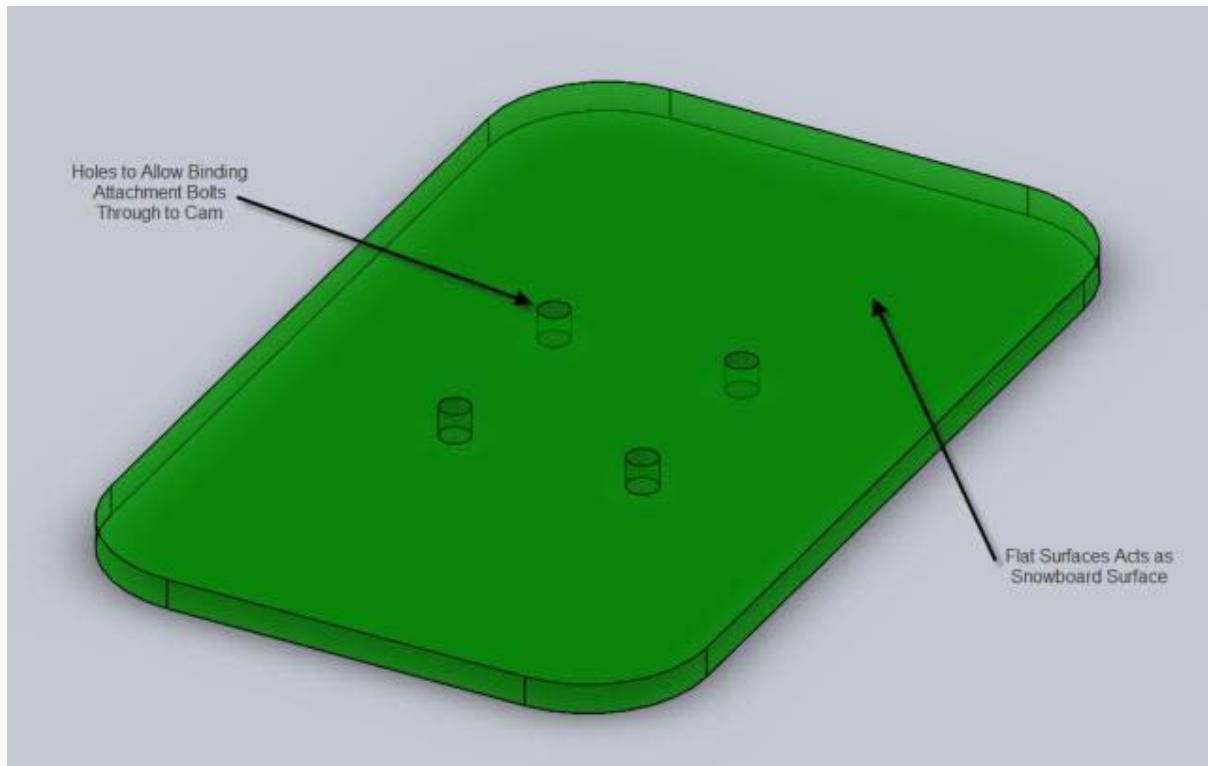


Figure 22: Binding Attachment Plate

The purpose of the binding attachment plate is to act as the surface of the snowboard. Ideally you could connect a binding directly to the cam without the binding attachment plate. However, the bottom surface of a snowboard binding is not a smooth surface and would therefore resist rotation and possibly cause damage to the system. The four holes line up with the four holes on the top of the cam as well as the holes in the bottom of the binding. The top plate is 5in x 8in x 0.25in in dimension.

3.1.5. Followers (*Ball Plungers*)

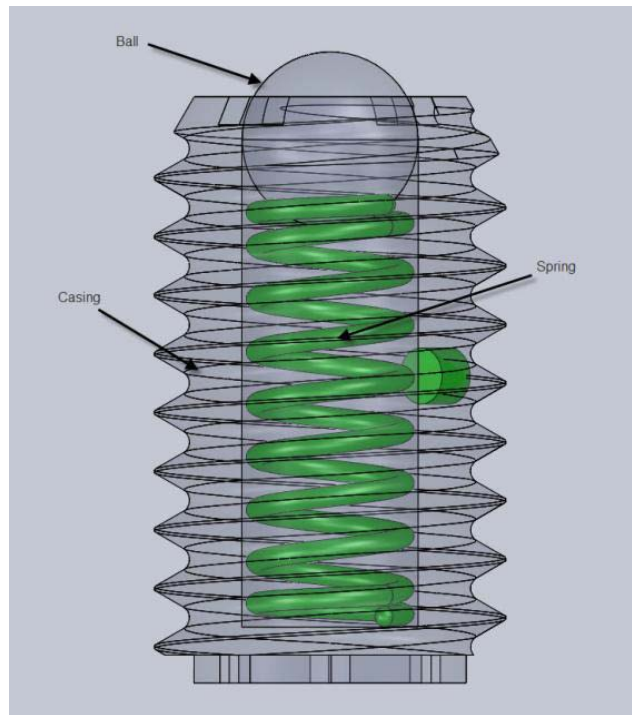


Figure 23: Ball Plunger

The ball plungers were purchased from Carr Lane Manufacturing Co. located in St. Louis Missouri. Both the casing and ball are made of stainless steel. The threads are 3/8-16. The length of the non-compressed system is 0.673 inches and the diameter of the ball is .187 inches. The initial force produced by the spring is 6 lbs and the final force is 21 lbs. The total travel of the ball is 0.048 inches. The ball plungers act as the followers in the cam-follower system. They prevent rotation at low torques and allow rotation at higher torques.

3.2. Post and Hole Tolerancing

Table 1: Standard Tolerance Limits

<u>Standard Tolerance Limits</u>		
<u>Diameter</u>	<u>Hole</u>	<u>Post</u>
4.865	+0.004	-0.0035
RC 6 Fit (Medium Fit)	+ 0.000	-0.0060
2.86	+0.007	-0.0090
RC 9 Fit (Loose Fit)	+0.000	-0.0135

Table 2: Diameters with Tolerance

<u>Diameters with Tolerance</u>			
<u>Diameter</u>		<u>Hole</u>	<u>Post</u>
4.865	Max	4.8690	4.8615
RC 6 Fit (Medium Fit)	Min	4.8650	4.8590
2.86	Max	2.8670	2.8510
RC 9 Fit (Loose Fit)	Min	2.8600	2.8465

Table 3: Actual Machined Diameters

Diameter	Part	Actual Diameter of Machined Parts	Within Tolerance?
4.865	Cam (Post)	4.860	YES
	Cam Pocket (Hole)	4.865	YES
2.86	Cam Post (Post)	2.849	YES
	Top Plate Hole (Hole)	2.885	NO

In order to ensure the proper fit between the parts, the Machinery's Handbook was used to find the ANSI standard tolerances which can be found in Table 1. The translation of those tolerances to the diameters of the parts can be found in Table 2. A medium fit was chosen for the outer diameter of the cam in order for the ball plungers to fit properly in the detents. If the fit was too loose, there would be too much "slop" in rotation of the binding. A loose fit was chosen for the smaller diameter in order to make assembly. As you can see in Table 3, the top plate hole was out of tolerance. This error was due to a lack of understanding of the function of the laser

cutter. When the Delrin™ part was cut in the laser cutter, it was unknown by the group that the laser cuts exactly on the intended line. This is a problem because the width of the cut is substantial enough to throw off the tolerance which is illustrated in Figure 24.

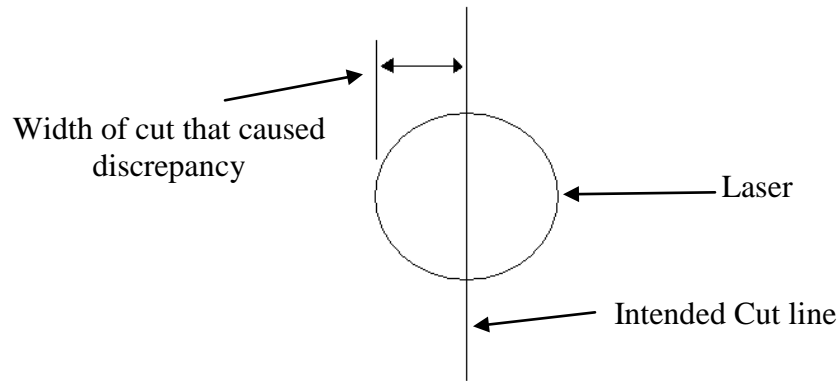


Figure 24: Laser Cutter Discrepancy

3.3.Finite Element Analysis

Finite element analysis was performed on each iteration of the assembly prior to the machining phase. The base plate was constrained by the cylindrical mounting bolts, with each additional part constrained to the previous according to assembly conditions. Once they were constrained, each individual part was evaluated in order to ensure that no riding conditions would place stress on the materials in excess of the yield stress. In addition, the total deflection of each part was evaluated to ensure that the assembly remained within operating tolerances through any forces applied during riding.

The assembly was created in Solidworks and then the geometry was imported into ANSYS 12. The material properties of 6061-T6 Aluminum and Delrin™ (POM) were assigned in the engineering data section. The entire problem was opened into ANSYS Mechanical in order to create a mesh and evaluate solutions. All 4 parts were meshed and constrained according to

assembly conditions. In order to get the best depiction of the true stresses, a large amount of nodes were used.

A line pressure equivalent to 750N (Knunz, 2001) was placed on the front edge (A) of the binding attachment plate as seen in Figure 25 below. A line pressure equivalent to negative 1350N (Knunz, 2001) was placed on the back edge (B) of the binding attachment plate as seen in Figure 25 below. These are forces normally exerted by a 75 kg rider going 10 m/s. The forces were recorded during a backside turn on a course with carving turns, an average slope of 19 degrees and hard packed snow.

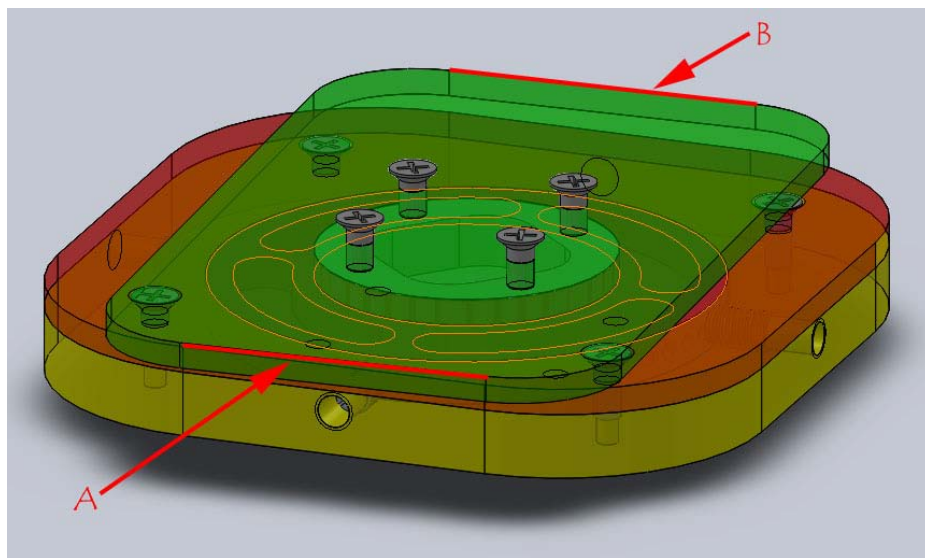


Figure 25: Assembly showing locations of line pressures used in Finite Element Analysis

3.3.1. Assembly Analysis

The figures below show the assembly of our binding-to-snowboard interface. When a snowboard is built, it is designed to absorb the impacts and forces from a rider on the snow. This being said, our interface had to be constrained to perform in a similar way to the snowboard itself and transfer the forces, moments, and torques from the binding to the board seamlessly. Stresses

and deformation of the assembly were calculated through finite element analysis. In Table 4 below you can see the number of nodes and elements as well as the maximum stress and deformation in each of the parts of the assembly.

Table 4: Finite Element Analysis solution data

Part	# nodes	# elements	Max Stress (MPa)	Max Deformation (mm)
Base Plate	87345	59234	35.768	0.43447
Top Plate	89342	61320	17.91	0.016455
Binding Attachment Plate	91045	58473	21.791	0.016661
Cam	90043	62094	17.163	0.055727

Because the assembly was designed much stronger than necessary, the stress concentrations were found to be highest where the bolts/plungers attached and at the pressure points from the binding attachment plate. These can be seen in the figures below. When the cam was designed the first time, it was shown to be much more robust than necessary and modifications were made. The top of the Cam was pocketed to reduce weight while still retaining the necessary strength.

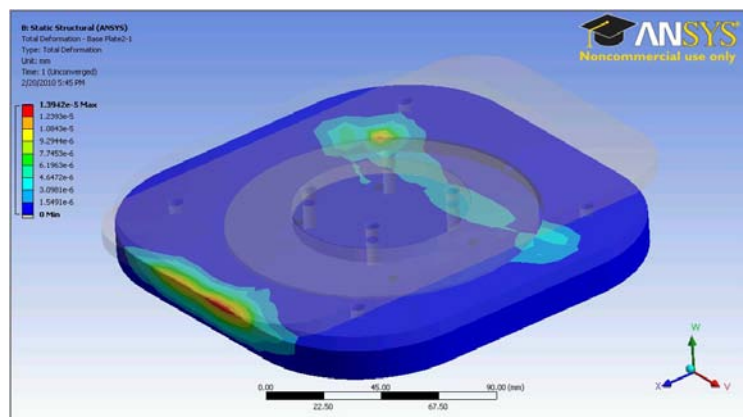


Figure 26: Base Plate deformation

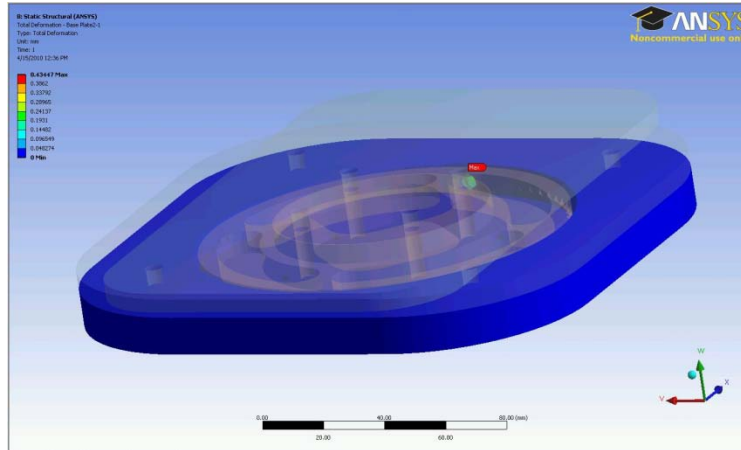


Figure 27: Base Plate Stress concentrations

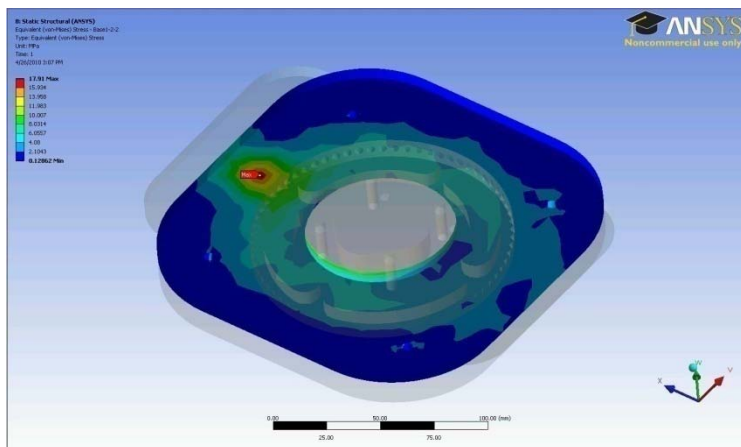


Figure 28: Top Plate Stress concentrations

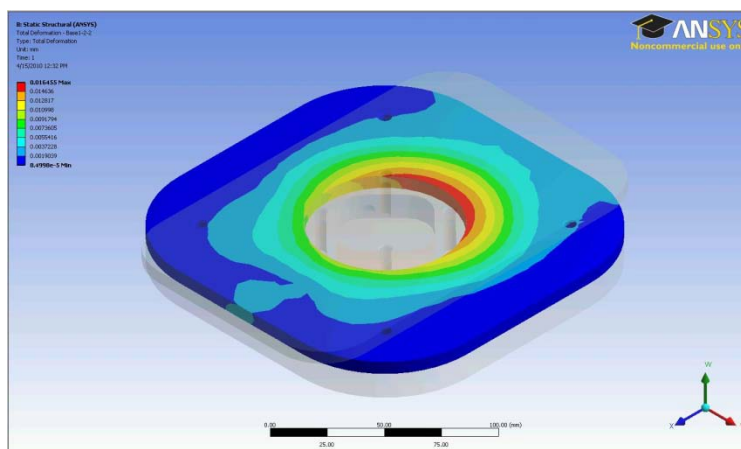


Figure 29: Top Plate deformation

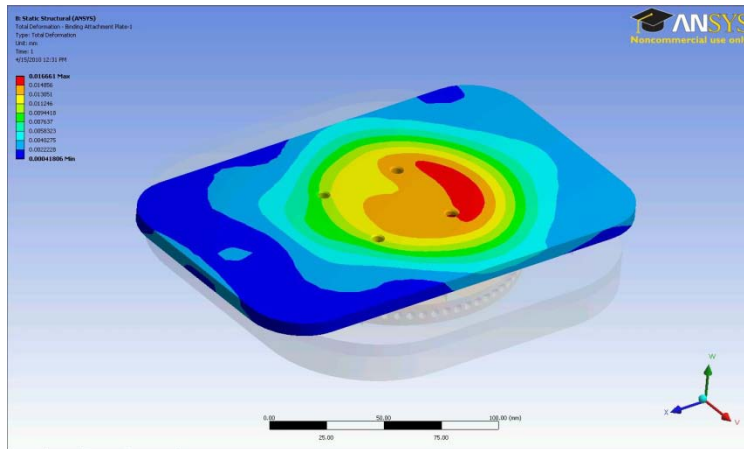


Figure 30: Binding Attachment Plate deformation

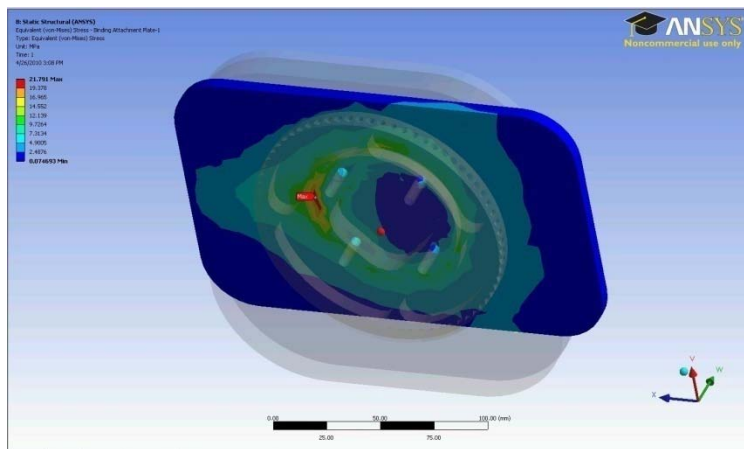


Figure 31: Binding Attachment Plate Stress concentrations

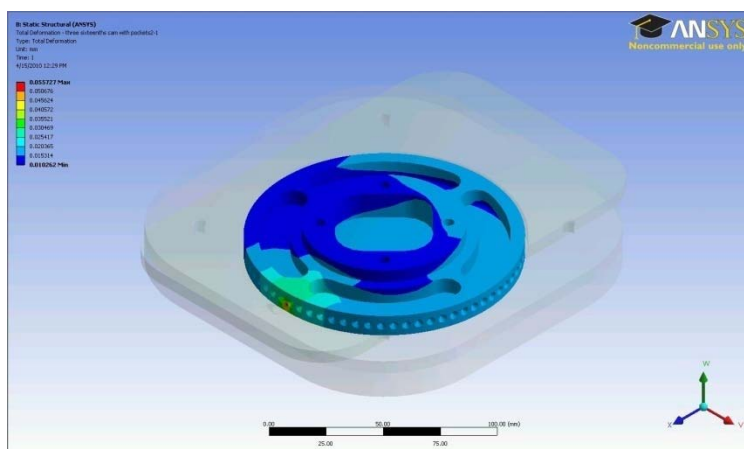


Figure 32: Cam deformation

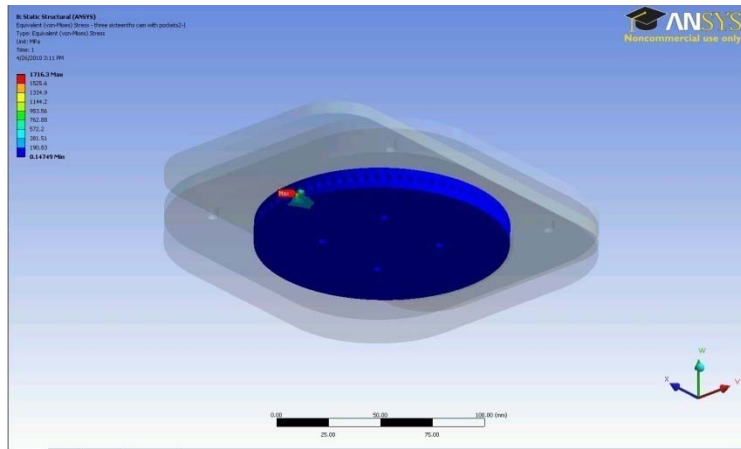


Figure 33: Cam Stress concentrations

3.3.2. Material Selection

Polyoxymethylene, commonly referred to as POM and known under DuPont's trade name Delrin™, was chosen as the material for the binding attachment plate, base plate, and top plate because of its mechanical properties, light weight, and machinability. 6064-T6 Aluminum was chosen as the material for the cam because of its low weight-to-strength ratio and machinability. The material properties for these can be found in Appendix 11.5.

4. Prototype Production

4.1. Machining

The prototype was manufactured based on the functional requirement of ease of manufacturing and the design constraint of a 4 pound weight limit. Aluminum was chosen as the material for the cam for its low cost, light weight and its machinability. Delrin™ was chosen for the other parts for its light weight and machinability as well, but it was also chosen for its self lubricating properties which helps reduce friction between the cam and the outer case.

The first part produced was the cam. In order to drill the holes around the outside perimeter of the cam, fixturing in the 4th axis had to be taken into consideration in the initial design. This was accomplished by leaving excess material on the top of the cam of which a hex shaped post was machined. This post allowed us to fixture the cam in the 4th axis chuck and successfully drill the holes. After the holes were drilled the cam was placed in a vice, the hex was machined off and the final cuts were made in the cam leaving us with the finished cam.



Figure 34: Machined Cam

The next parts produced were the two-dimensional Delrin™ parts. These parts were cut with a laser cutter and the chamfers were added appropriately using a drill press.

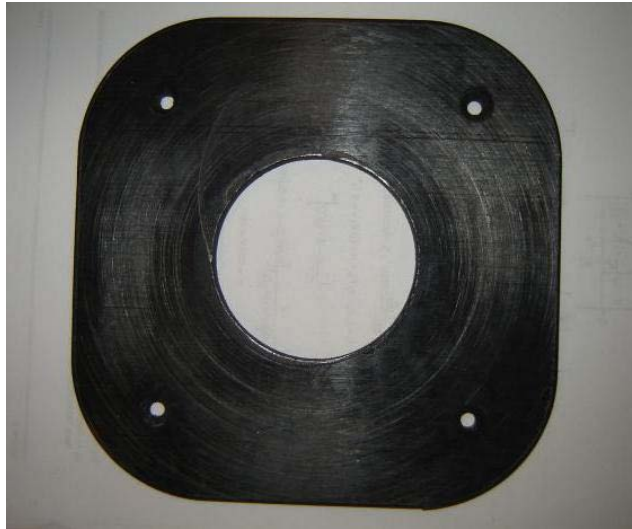


Figure 35: Laser Cut Top Plate



Figure 36: Laser Cut Binding Attachment Plate

The final part produced was the base plate. This part was manufactured using the Haas CNC machine.



Figure 37: Machined Bottom Plate

4.2. General Assembly

The prototype is assembled by first attaching the base plate to the snowboard using four M6x14 bolts. These bolts screw into the standard holes found on all snowboards.



Figure 38: Bottom Plate Assembly

The second step is to insert the cam into the base so that the post points upwards.



Figure 39: Cam Assembly

The third step is to place the top plate on top of the base plate and cam so that post goes through the center hole and the four holes in the top plate line up with the four holes in the bottom plate. Next insert the four 1/4-20 bolts into the four chamfered holes and screw them in tight.



Figure 40: Top Plate Assembly

The fourth step is to attach the binding attachment plate and the binding. This is done by placing the binding attachment plate on top of the cam post and lining up the four holes. Next, the binding is placed on top of the binding attachment plate and the slots or holes in the bottom of the binding are lined up with the four holes in the binding attachment plate and cam. Lastly, four 1/4-20 bolts are screwed into the holes.



Figure 41: Binding Attachment Plate Assembly Step 1

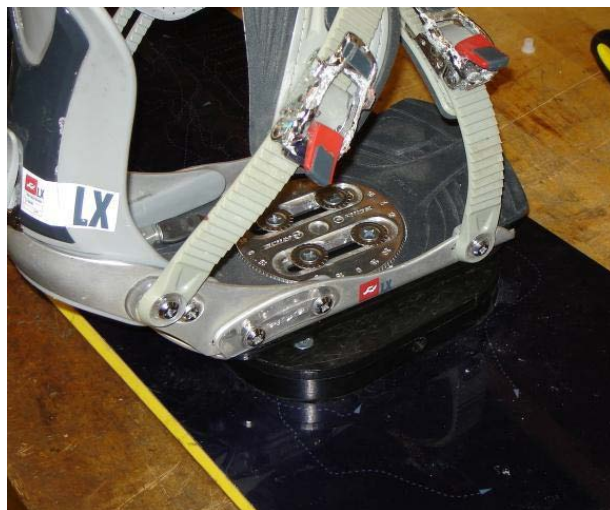


Figure 42: Binding Attachment Plate Assembly Step 2

The final step of the assembly is to insert the ball plungers into the 3/8-16 holes located on the four sides of the base plate. This must be done very carefully in order to ensure that they

are inserted properly. If inserted too deep the casing of the ball plunger will damage the cam. If not inserted enough, the plungers will not exert a sufficient force and the cam will rotate too easily. Once the plungers are in, assembly is completed.

5. Testing of the Final Design

5.1. Bench Test

In order to test the design to ensure that it was functioning properly before on-slope testing, a ski binding torque tester was used to measure the torques required to rotate the binding. The device was tested by first inserting one steel ball plunger, then a second was inserted, followed by a third and fourth, testing the torque each time a new plunger was inserted. The results were as follows:

Table 5: Bench Testing Results

Number of Ball Plungers	Maximum Torque Required to Rotate (Nm)
1	10
2	12.5
3	15
4	20

Following the testing of the steel ball plungers, Delrin™ ball plungers were also tested. The Delrin™ ball plungers produced the same results; however, when the prototype was disassembled it was found that the sharp edges of the aluminum detents were cutting away at the Delrin™ balls. This meant that Delrin™ ball plungers could not work with the current design as the torque required to turn the binding would deteriorate as the Delrin™ balls were cut away.

Based on the results, it was determined that it would be optimal to use four steel ball plungers for the on slope testing. Although the required torque of 15 Nm is achieved using three ball plungers, it is the maximum force measured, which means that it only achieves the 15 Nm at its peak. In other words, there is some movement, or “slop”, in the device at torques lower than 15 Nm.

Ideally, we would like to have produced an Angle vs. Torque graph to show the results of this bench testing. However, the small size of the angles between the detents and the low

resolution of the measurements of the torque wrench made it impossible to take accurate measurements and produce useful data.

5.2. On Slope Testing

On April 21, 2010, the prototype was tested at Killington Mountain in Killington, VT. This site was chosen because it was the only ski area still open in the general area. The design was tested on both flat ground and on sloped ground.

5.2.1. Test 1: Flat Ground

The prototype was first tested on flat ground to ensure functionality while “skating”. “Skating” is a term used in snowboarding to describe the act of having only the front foot strapped in while pushing on the ground with the non-strapped in foot, similar to the act done on a skateboard. The rider, Nate Brown, noted that although at first it felt kind of awkward because he wasn’t used having his foot straight forward, after a couple pushes it became much easier and the stress on his knee felt greatly reduced. Another feature that he noticed was that while skating when he comes to a slightly down hill section he generally likes to put his rear foot back on the board near the rear binding. This would be uncomfortable with the front foot facing forward. However, once his back foot was back on the board he was able to easily rotate his front foot back to normal riding position and glide across the snow comfortably.

5.2.2. Test 2: Downhill

Following the flat ground testing, the prototype was tested on a small downhill section. Nate Brown took three runs down the easy section of the slope. He reported that on the first run it felt kind of awkward because he knew it could rotate and focused on trying not to make it turn.

However on the second and third runs, he became more relaxed and returned to his normal riding form. He reported no rotation while riding on any of the runs.

5.2.3. Test 3: Bench Test after Use

After the flat ground and downhill testing, the prototype was torque tested once more to check for repeatability. The results were exactly the same as the results from the previous bench testing.

5.3.EMG Testing

In order to evaluate the effects of the device on muscular contraction, electromyogram testing was performed using AcqKnowledge 3.9.1 software. A BioPac Systems MP100 analog data acquisition unit was connected to 3 EMG-100 modules, each measuring the voltages across specific muscle groups. Electrodes with Shielded leads were connected to these EMG modules. The data was acquired at 200 samples per second. Channel 1 was connected to the Tibialis Anterior, channel 2 was connected to the Quadriceps Major, and channel 3 was connected to the Hamstring as shown in Figure 38 below.

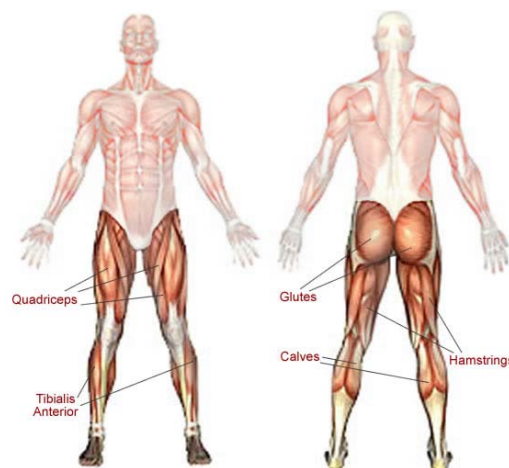


Figure 43: Leg Muscles (<http://www.greatweightlifting.com/images/LegMuscles.jpg>)

5.3.1. Test 1 – Control test

In our first test we connected the leads to a group member and acquired data while he was standing still, then as he flexed his muscles. This test was done in order to establish a baseline of values, or a control for the experiment. The signals from the muscles can clearly be seen in Figure 44 below.

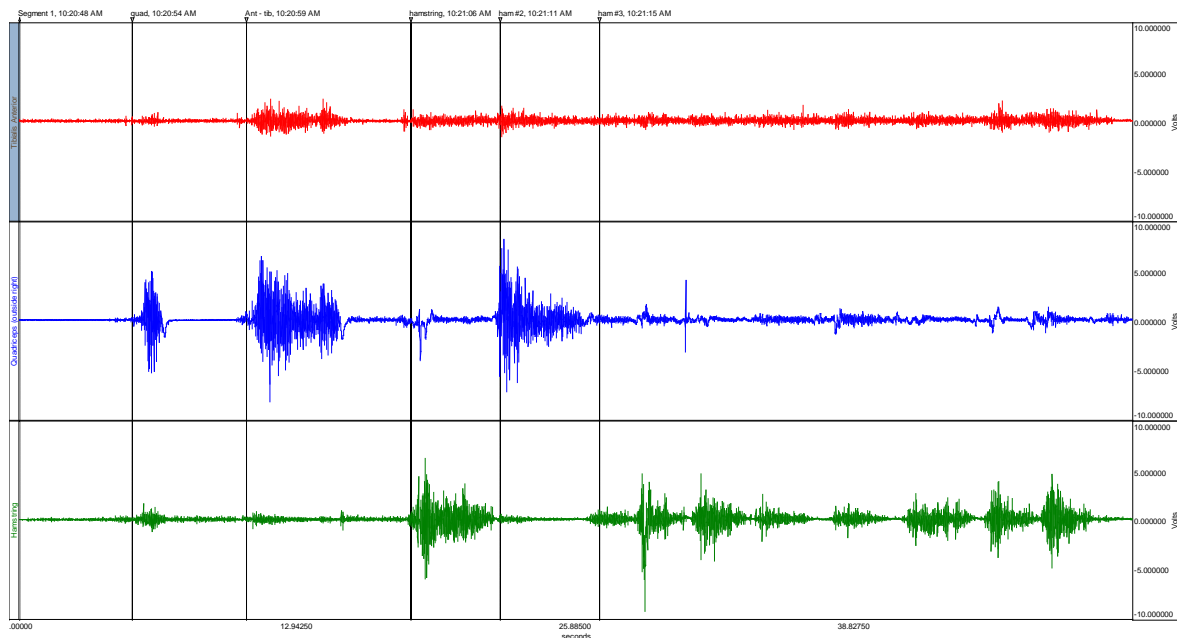


Figure 44: Control Group (not strapped into the board)

When the quadriceps was flexed, there was clearly a spike in the channel 2 data, shown in blue. The Tibialis Anterior is shown in red, and the Hamstring is shown in green. These channels both showed a clear spike when they were flexed as well. This provided a clear set of values to make informed comparisons from on the other tests.

5.3.2. Test 2 – Rotating the foot in place from normal riding position to the forward facing position and then back to the original position.

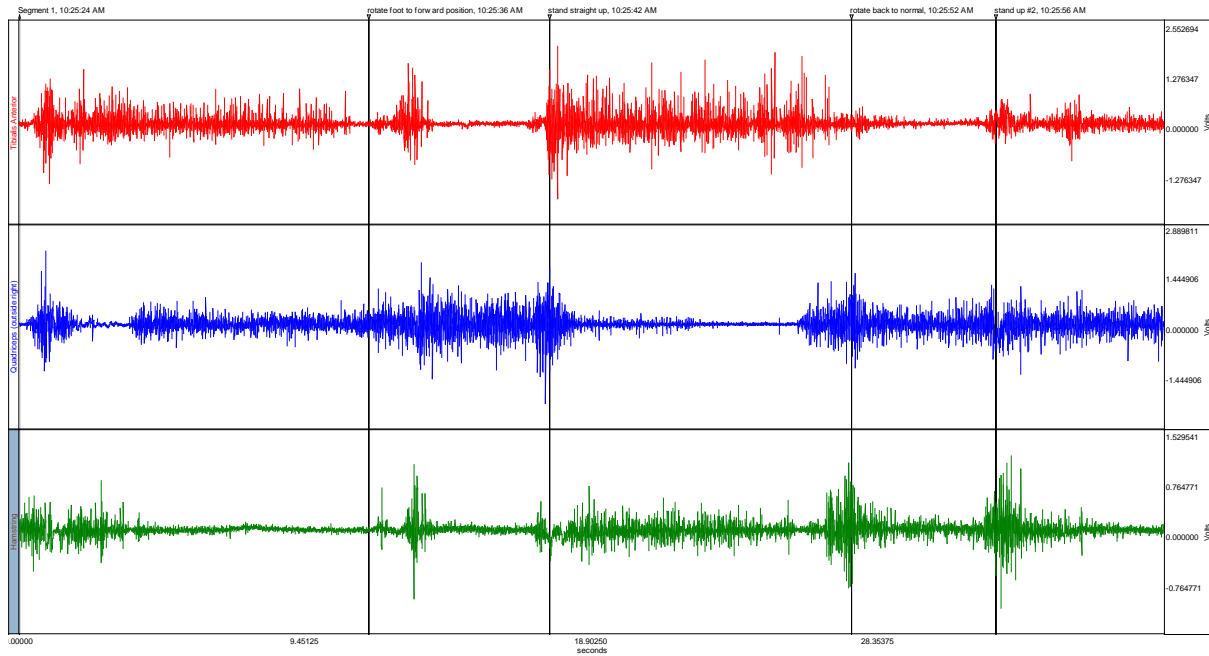


Figure 45: Standing on the board then rotating foot

As you can see from Figure 44 above, in the normal position, most of the contraction is seen in the quadriceps and Tibialis Anterior muscles. This is because the leg is put in such a position that the Quadriceps and the Tibialis Anterior are both flexed to support the knee. The hamstring experiences little to no contraction in this position.



Figure 46: Binding in Forward-Facing position

When turning the binding to the forward facing position (as seen in Figure 45 above), the Quadriceps muscle is doing most of the work throughout the turn but it must recruit the help of the hamstring and Tibialis Anterior muscles to overcome the initial force necessary to move the ball plunger from the first detent. Once the binding is in the new position, the hamstring and the Tibialis Anterior take most of the load while the quadriceps does not do much work at all.

Turning the binding back to the original position (Figure 42 below) shows the quadriceps and hamstring working initially to rotate the binding, but the Tibialis Anterior shows little to no contraction.



Figure 47: Binding in Normal Position

This test serves to show that not only are multiple muscles used, but also that multiple muscles perform different tasks in turning the binding and supporting the leg.

5.3.3. Test 3 – Skating with the binding in the normal position versus the forward facing position.

The two graphs below show the muscle impulses when a boarder is skating along flat ground. Figure 43 depicts 4 pushes while skating with the foot in the original position whereas Figure 44 depicts 4 pushes while skating with the foot in a forward-facing position.

Both the mean voltages and the Peak to Peak ranges of the muscles in Figure 44 show a clear trend. You can see these numbers in Table 4 below. All three muscles are doing less work while skating with the foot in the forward facing position. A twenty-five percent drop in voltage across the Hamstring was recorded along with a five-percent drop across the Quadriceps. The

Tibialis Anterior showed similar voltages between the normal and forward-facing positions because the lower leg remains constantly dorsiflexed throughout the test.

Table 6: Voltages across muscles during skating

Voltage (V)	Skating - Normal Position	Skating - Forward Facing Position	Forward Facing Position as a percentage of Normal Position
Quadriceps Mean	0.15169	0.14426	0.951018525
Quadriceps Peak-to-Peak	7.44781	6.65222	0.893177995
Tibialis Anterior Mean	0.14209	0.14095	0.991976916
Tibialis Anterior Peak-to-Peak	8.7851	4.06738	0.462986193
Hamstring Mean	0.14566	0.10968	0.752986407
Hamstring Peak-to-Peak	6.48804	2.5674	0.395712727

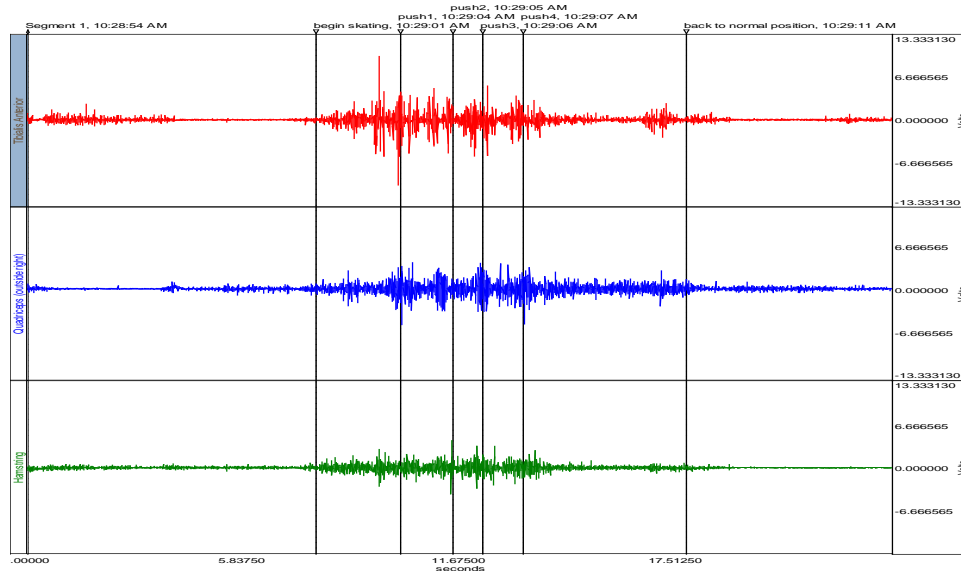


Figure 48: Skating, normal position

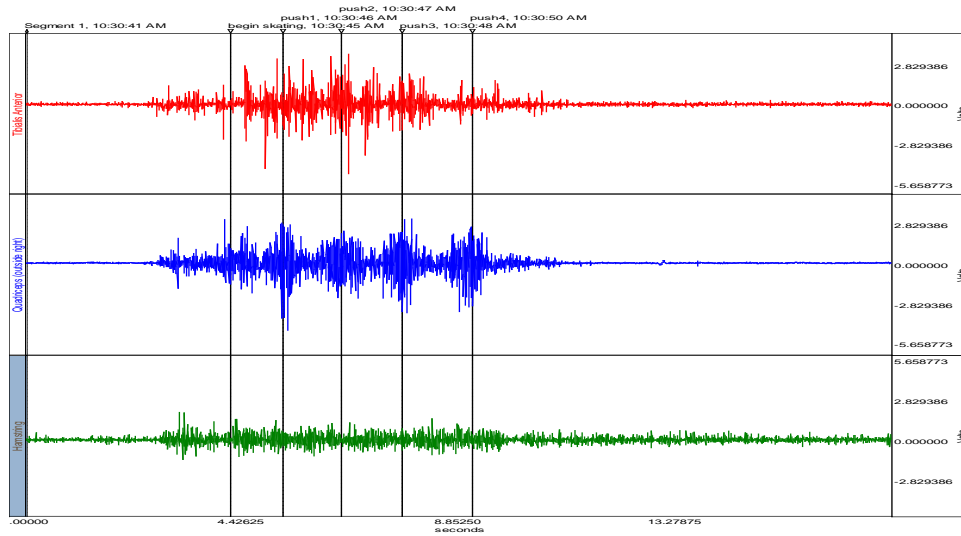


Figure 49: Skating, new position

5.3.4. Test 4 – Comparing the effects of foot position on muscle contraction while riding on a chair lift.



Figure 19: Lift Simulation, normal foot position



Figure 20: Lift simulation, forward foot position

Five consecutive sixty-second tests were performed simulating riding on a chair lift. Though the data from this test proved to be mostly inconclusive, the subject claimed to feel

different levels of comfort and discomfort from the multiple positions that the board was in. The graphs from this set of tests can be found in Appendix 11.4 along with a full table of values.

In the first test the board was allowed to hang freely with the foot in the normal position. In this test the muscle activity in the Hamstring decreased slightly over the 60 second period, but the subject also stated that he felt discomfort in his Quadriceps as the test progressed.

In the second test the subject was allowed to hold the board up with his opposite foot to take some of the weight off of his right leg. The attached foot was still in the normal position. This test showed that the activity in the Quadriceps increased over the course of the ride. This can be attributed to the bend in the knee approaching ninety degrees because of the support from the opposite foot. As that angle decreases, the more of the Quadriceps is activated. The subject also stated discomfort in the muscles on the outside of the knee.

In the third test the subject's foot was in a forward-facing position and the board was hanging freely. The subject stated that this position was much more comfortable than either of the two previous despite similar muscle activity.

The last two tests were performed with a simulated bar for the subject to rest his board on. These were the only two out of the five performed that yielded comparable results. The first test, performed with the foot in the normal position showed significantly higher standard deviations in the data than the second test, performed with the foot in the forward-facing position. This can be attributed to miniscule muscle twitches used to stabilize the board and keep the leg in a comfortable position. The test in the forward-facing position yielded nearly a sixty percent smaller deviation, from which it can be deducted that the leg is much more relaxed.

6. Recommended skill level of user

The skill level of snowboarders varies anywhere from beginners who have never seen snow before to experts on the slopes who have been riding all of their lives. Given this broad range of skill levels, a binding to snowboard interface such as the one designed by this MQP team would cater to anyone from Level 1 through level 5 on the Snowboard Ability Chart shown below. Because the device makes it much easier to move on flat ground and more comfortable to ride on lifts, people new to the sport would appreciate it and benefit greatly from incorporating it into their snowboard setup.

On the same token, intermediate to advanced riders will also like the adjustability that the interface gives you. This adjustability is a major benefit because it allows the rider to change the angle of their front foot depending on what kind of terrain they are riding on at the time. The front foot is the control foot when snowboarding and most of the weight is kept on the back leg, so giving the rider the ability to fine-tune their front control foot is a major bonus.







BEGINNER PROGRAMS	
	LEVEL 1: FIRST TIME SNOWBOARDER Never snowboarded before.
	LEVEL 2: NOVICE Able to slide and stop, both front-side, backside and attempting to link turns on gentle terrain.
	LEVEL 3: COMFORTABLE NOVICE Able to link sweeping pivot turns on gentle green terrain and ready to venture onto all green runs.
INTERMEDIATE/ADVANCED PROGRAMS	
	LEVEL 4: INTERMEDIATE Can snowboard comfortably on all green runs, and some blue runs. More difficult blue runs are sometimes a challenge. Would like to explore more varied terrain.
	LEVEL 5: ADVANCED Able to link turns on all blue runs and easy black runs. Learning, short turns, off piste terrain, small jumps, powder and difficult terrain.
	LEVEL 6: EXPERT Enjoy the challenge of snowboarding in control, in all conditions and terrain and want to refine these skills.

Figure 50: Snowboard Ability Chart (http://www.whistlerblackcomb.com/rentals/school/ability_snowboard.htm)

7. Iterations

With the completion of the slope test and laboratory tests many different design changes for future iterations of this prototype were made. The prototype was success as far as the functional requirements are concerned, but many possible improvements were apparent. Certain aspects of the design were overlooked during the preliminary tests that can be iterated to create a more efficient and marketable design. These iterations to the design include reductions in the overall mass, reduction of the total height, and material selection of the cam.

The first future iteration that should be taken into account is the overall mass of the prototype. The prototype met the design constraint of remaining under 4lbs, but still weighed around 3lbs for a single binding interface. The addition of another for the back foot would increase the weight of a snowboard by 6lbs and could be considered a marketable restriction. Riders may perceive the increased mass of the snowboard as not worth the convenience of hands-free rotation of the binding.

Future iterations should include the removal of unnecessary material from the base plate, cam, top plate, and binding attachment plate. The removal of the material may have a negative effect on how the loads are transferred throughout the system. It is suggested that pockets of material removed should be in the shape of a quasi square. Through preliminary research it was found to be the most stable shape to withstand loads and stresses. The reduction of material should be sought after to improve the marketability of the design.

The overall height of the snowboard can also be considered a marketable restriction to this initial prototype. Snowboarding is a sport where an emphasis on the style of the board is just as important as the overall function. Many companies focus on creating fashionable designs and

this can be seen on boards, bindings, and snowboard apparel. This initial prototype is just over a 1in and may not be aesthetically pleasing to the demographics snowboard companies focus upon. The current prototype's height is dependent upon the diameter of the preloaded ball plunger device used. The preloaded ball plungers come in a variety of sizes, but each size is able to only exert a specific range of loads. Through preliminary tests it was determined that the 3/4in diameter preloaded ball plunger needed to be used to exert the necessary loads to complete the functional requirements. A future iteration to decrease the overall height may use a different preloaded device or method of exerting the necessary loads.

The most apparent issue after the testing of this prototype is the wear on the prototype's cam after relatively minimal use. During the preliminary tests of the prototype preloaded ball plungers with a Delrin™ tip were used. The ball plunger Delrin™ tips began to erode after several rotations because of the sharp edges along the tops of the conical detents. It became evident that the Delrin™ tipped ball plungers could not be utilized with a cam made of this aluminum alloy.

On the other hand, the preloaded ball plungers with a steel ball tip that were used during the bench, mountain, and EMG testing created noticeable deformation along the side of the cam. It became apparent that a cam designed from this aluminum alloy is not able to withstand the tensile and shear stresses created with the use of steel tipped ball plungers. Future iterations should explore the use of different materials in the cam and plunger tip in order to prevent this rapid deterioration.

8. Discussion

The designs completed by MQP teams at WPI during the springs of 2007 and 2009 have the ability rotate fully 360° on demand. Both teams utilized the cam follower systems with the springs driving a follower. When a torque is applied by the user the springs compressed allowing the system to rotate about the cam profile. The teams allowed a stable rotational position every 90° for the user. The addition of a stable position located 90° away from the riding position allowed a greater comfort level experience by the user during travel to and from the chair lifts. This rotational capability not only provides greater comfort but could also reduce the chance of flat terrain and chair lift injuries.

While both of these MQP teams successfully designed prototypes that were able to rotate to these positions, more can be changed in these designs to improve the experience for the user. By allowing an increased number of stable rotational positions, riders can adjust their front foot positions with just a twist of the ankle to their individual comfort level. The new rotational possibilities would increase the marketability of such a product for sale on the snowboard market.

These past MQP teams provided great base designs for rotational bindings and suggested possible improvements to their designs to help create an effective marketable product. The MQP team from 2008-2009 suggested the use of composite materials to lighten the mass of the design. The team stated the user became noticeably tired after riding for an extended period of time with the additional weight of the prototype. This improvement could allow rotational bindings to appeal to a larger demographic.

The objective of creating a hands-free rotatable snowboard binding interface was accomplished with the use of axiomatic design. Through the axiomatic design process a final design for the rotatable binding interface was quickly achieved. Originally preloaded spring plungers and a cam with slots along its outer surface were considered as a design. Through the axiomatic design process, flaws were found with this original design and eliminated creating a new design. The new design utilized a preloaded ball plunger and a cam with conical shaped detents. Through the testing process of this design, it was proven that this design successfully completed the objective of creating a rotatable binding interface.

During the laboratory testing process the torque measurements on the interface with the use of three preloaded ball plungers successfully met the objective of creating 15Nm of torque. The design was also tested with the use of four preloaded ball plungers and created 20Nm torque. It was decided that four ball plungers would be utilized for the final design to ensure the system would only be rotatable on demand of the user.

In order to provide multiple rotational positions with the use of preloaded ball plungers, conical detents were designed. These conical detents milled along the outer profile of the cam also provided a way to allow multiple rotational positions for the binding. The only limitation to the number of rotational positions was the diameter of the cam and detents. The final design resulted in thirteen different rotational possibilities for the binding.

In completing the objective of maintaining a design that remains under the weight constraint, material analysis was completed on a wide range of plastics. The material analysis resulted in the choice of the Acetyl resin Delrin™ for many of the components of the prototype. The Delrin™ material was found to be able to withstand the loads and stress applied during

normal snowboarding conditions, but was significantly lighter in mass than aluminum alloys used by previous project groups.

In order to complete the objective of remaining under 1.5in in total height, the interface was designed dependent on the diameter of preloaded ball plungers. Through preliminary laboratory calculations it was found that the use of $\frac{3}{4}$ in diameter ball plungers was needed in order to produce the necessary loads against the conical detents. This allowed the total height of the final design to be 1.25in and follow the height constraint objective.

A problem noted in the design was the deformation of the cam's outer surface after use caused by the steel ball plungers. With this overlooked issue, several recommendations could be made in regards to the deformation. The use of a different cam material that can withstand the stresses caused from the loads of the steel tipped ball plungers could help reduce this issue. Another suggestion is the use of different preloaded devices that would not cause the deformation of the cam made of aluminum alloy.

Overall, the designed snowboard binding interface performed as originally intended. Rotation for all the rotational possibilities performed as expected. The different rotational positions during the slope and EMG testing allowed the user to experience an increased comfort level during the flat ground and chair lift use. The EMG results showed a decreased amount of muscle activity required by muscle groups for flat ground use in the forward position, but proved inconclusive for use on the chair lift. Improvement of the material used for the cam or the use of different preloaded devices would only improve upon an already successful design.

9. Conclusions

- Created a rotatable snowboard binding interface that prevents rotation under 20 Nm of applied torque, but rotates freely above 20 Nm of applied torque.
- The binding to snowboard interface was exactly three pounds, which was under the four pound weight constraint.
- The thickness of the interface was 1.125 inches, which was under the 1.5 inch height constraint.
- The binding to snowboard interface allowed for an increased number of different rotational positions to fifty-two, of which thirteen are utilized during typical operation.
- The outer surface of the cam experienced deformation after minimal use caused by the steel-tipped ball plungers.
- EMG testing results showed that there was a significant decrease in muscle activity while skating with the front foot rotated parallel to the board versus perpendicular.

10. References

Buzbee, Douglas C. Freely rotating step-in snowboard binding. Patent 6022040. 02 Aug. 2000. Print.

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White, Rick. Rotatable snowboard boot binding apparatus. Patent 7571924. 11 Aug. 2009. Print.

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11. Appendices

11.1. Prototype Production Steps by Step

11.1.1. Cam (aluminum)

11.1.1.1. Fixturing

- 11.1.1.1.1. Started with 5 inch round stock clamped in regular vice
- 11.1.1.1.2. Machined the post and a hex protruding from the post
- 11.1.1.1.3. Flipped it over and clamped the hex in the vice to face the bottom and machine the outside profile.
- 11.1.1.1.4. The cam was then clamped into a 4th axis device using the hex so that the holes on the outside perimeter could be drilled using the VF4 Haas CNC machine.

11.1.1.1.5. It was then clamped in the vice again, the hex was machined off and the four holes were drilled on top.

11.1.1.1.6. Used the table top tapping device to thread the four holes.

11.1.1.2. Tooling

- 11.1.1.2.1. A three inch face mill was used to machine the hex and the post.
- 11.1.1.2.2. A half inch end mill was used to face the bottom of the cam as well as create the outside profile.
- 11.1.1.2.3. A half inch drill with a 90 degree tip was used to drill the holes on the outside profile.
- 11.1.1.2.4. A three inch face mill was used again to machine off the hex
- 11.1.1.2.5. A #7 drill bit was used to drill the four holes on top.
- 11.1.1.2.6. A ¼-20 tap was used to thread the holes.

11.1.2. Binding Attachment Plate and Top Plate (Delrin™)

11.1.2.1. Both parts were cut using the school's laser cutter (thickness .25 inches)

11.1.2.2. All holes were then threaded using the table top tapping device and a ¼-20 tap.

11.1.2.3. The holes on the Top Plate were then chamfered in the VF4 Haas CNC machine using a half inch drill bit with a 90 degree tip.

11.1.3. Bottom Plate (Delrin™)

11.1.3.1. The Bottom Plate was too thick (.625 inches) to be cut using the laser cutter

11.1.3.2. First the square stock was clamped in a vice and the center hole was cut out using an end mill. The four holes in the bottom, as well as the four holes on top, were also drilled out.

11.1.3.3. The stock was then bolted to a scrap piece of plastic using the four holes in the bottom and the outside profile was machined.

11.1.3.4. Next the four holes for ball plungers were drilled out.

11.1.3.5. Finally, all holes were threaded to the appropriate dimensions.

11.1.4. Purchasing Information

- 11.1.4.1. All screws were purchased at Home Depot and the Ball Plungers were purchased through CarrLane.

11.2. Problems

While producing this prototype, we did run into a few problems. The first issue we encountered was learning how to use the Haas CNC machines. It was difficult for us to find somebody who had the time to teach us as well as find available lab time. The second problem that we had was a fixturing issue. While clamping the cam in the fourth axis chuck, there was a miscommunication which led to the cam not being clamped tight enough. While drilling the holes around the circumference, they began to move out of alignment and the part was unusable. The third issue involved the laser cutter. While cutting the first two-dimensional part, the Delrin™ caught on fire. The operation was stopped because it was unknown that the self lubricating property of Delrin™ would create this effect. A week of production was lost until the event was investigated. The final issue we had during production was with tolerancing. The intended cam dimensions did not match the actual cam dimensions. A similar issue was encountered with the Delrin™ base plate. Full details can be found in the tolerancing section above.

11.3. Patents Referenced

White, Rick Albert. "Snowboard Rotatable Binding Conversion Apparatus." US Patent 6575489. 10 June 2003.

Abstract

A snowboard rotatable binding conversion apparatus that is inserted between and attaches to a snowboard and a boot binding to render the boot binding rotatable in relation to the snowboard. The snowboard rotatable binding conversion apparatus includes a base, an engaging plate which sandwiches the base between the engaging plate and a snowboard, a top plate which sandwiches the engaging plate between the top plate and the base, an engaging element which engages an engaging slot in an engaging plate, an engaging bar which movably secures the engaging element to the base, a tension bar that provides tension to the engaging element, a tether attachable to the engaging element, and a plurality of screws and screw-receiving holes to attach the engaging bar to the base, the engaging plate to the snowboard, and the top plate to the base.

Drako, Dean M. "Snowboard Binding Rotational Mechanism." US Patent 6923454. 2 August 2005.

Abstract

A mounting assembly in accordance with the invention provides rotational adjustment of a board binding, such as a binding of a snowboard, wakeboard, or the like, without the use of external tools. A spacer plate which enables the mounting of the binding in a position above the board is combined with a mechanism which can change its thickness on demand, thereby locking or unlocking the binding from a freely rotatable position.

Cole, III, Charles D. "Freely Rotatable Binding for Snowboarding and Other Single-board Sports" US Patent 7059614. 13 June 2006.

Abstract

This involved the design of a freely rotatable binding base assembly for use on a board used in single-board sports such as snowboarding and slalom water skiing. A binding assembly mounted on and movably secured to the board, and is adapted to receive a conventional boot as worn by a rider. Additional features include a locking means for selectable blocking rotation, and a clutch for braking rotation by applying side loading to the board.

Buzbee, Douglas C. "Freely Rotating Step-in Snowboard Binding" US Patent 6022040. 8 February 2000.

Abstract

An improved snowboard binding system allows the snowboarder to maintain full control of the snowboard while also allowing the snowboarder to rotate the feet during the operation of the snowboard without the requirement of manual adjustment. A binding base (22) is attached to the snowboard and contains a circular, downward-facing surface (23) having several discontinuities. A boot catch structure (26) is attached to the user's boot and has a corresponding number of upward facing planar surfaces (27) that fit into the base surface discontinuities. Engagement of the binding is accomplished by the insertion of the boot catch into the binding base and relative rotation of the two parts. The binding system is equipped with a locking plate (24) that guards against accidental release of the binding system.

White, Rick. "Rotatable Snowboard Boot Binding Apparatus." US Patent 7571924 11 August 2009.

Abstract

A rotatable snowboard boot binding includes a boot plate with a toe end, a heel end, an aperture, and a cutout, a vertical support connected to the boot plate, a boot binder, an engaging plate, with a top portion with a perimeter edge, a bottom portion, and attachment holes, where the bottom portion includes a perimeter edge with engagement slots and the top portion perimeter edge overhangs the bottom portion perimeter edge, and a latching device fitting moveably within the cutout in the boot plate and able to be activated with one or more engagement slots in the engaging plate.

11.4. EMG Testing Results

11.4.1. Test #4 Results and Graphs

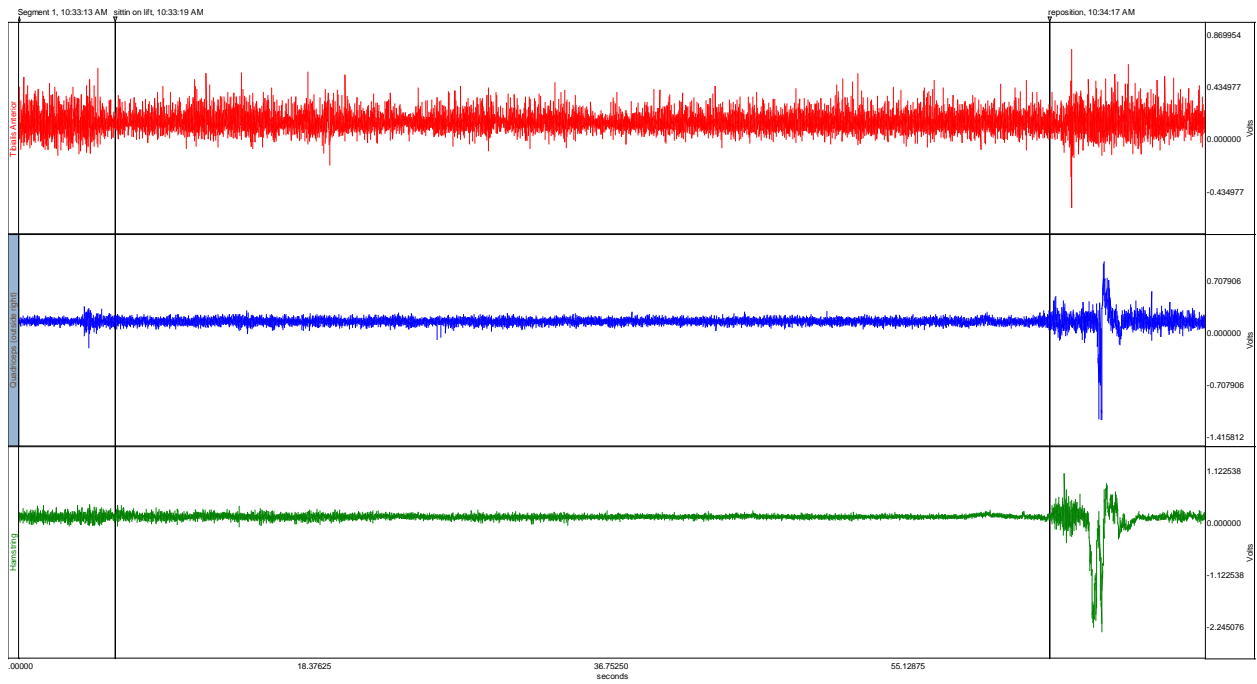


Figure 51: Lift ride – normal position, no hold, 60 seconds

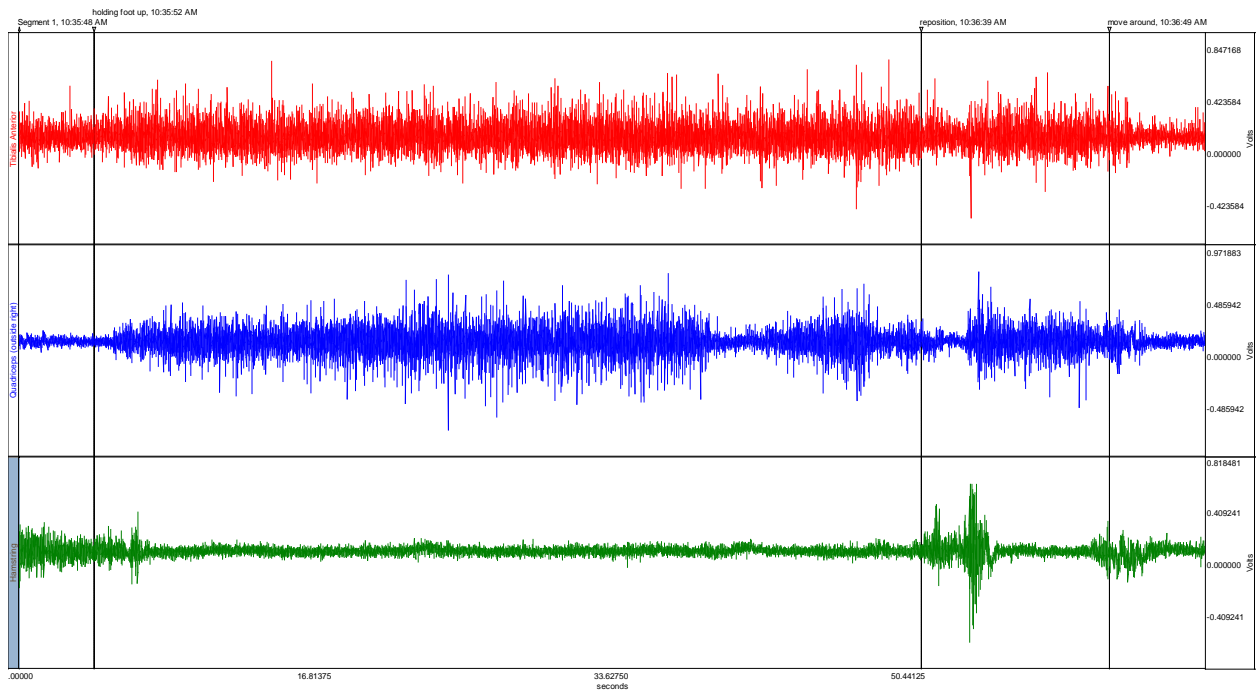


Figure 52: Lift ride – normal position, hold board up, 60 seconds

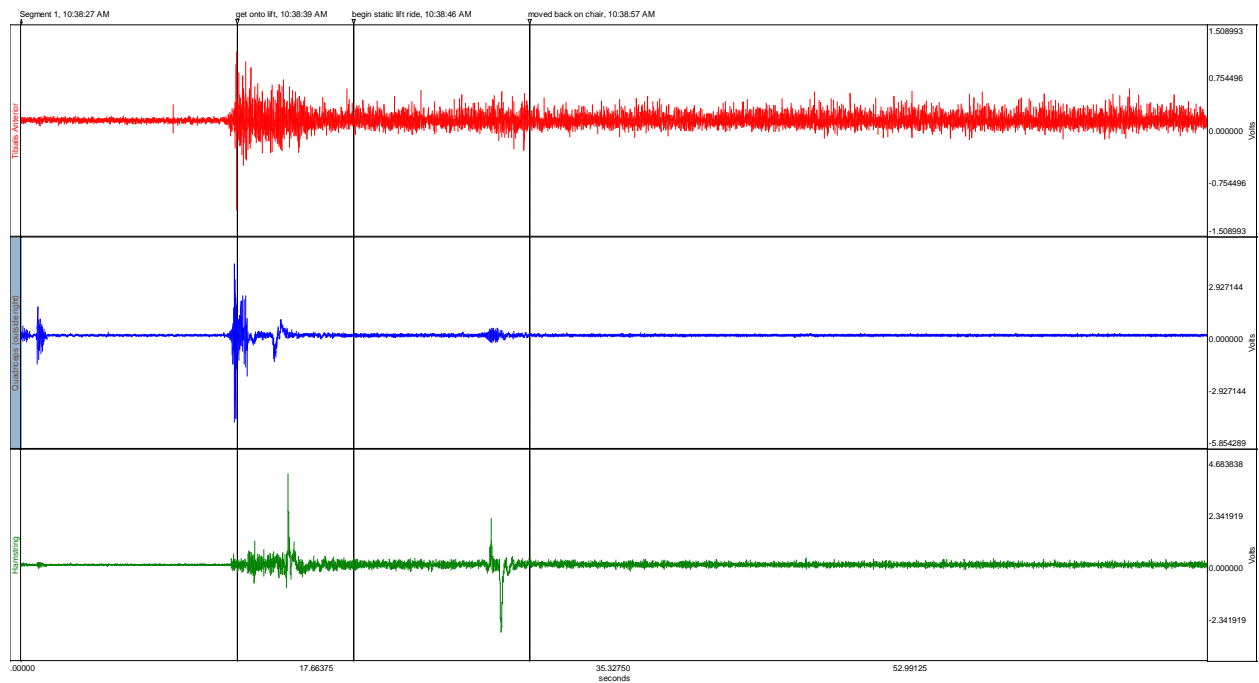


Figure 53: Lift ride – new position, no hold, 60 seconds

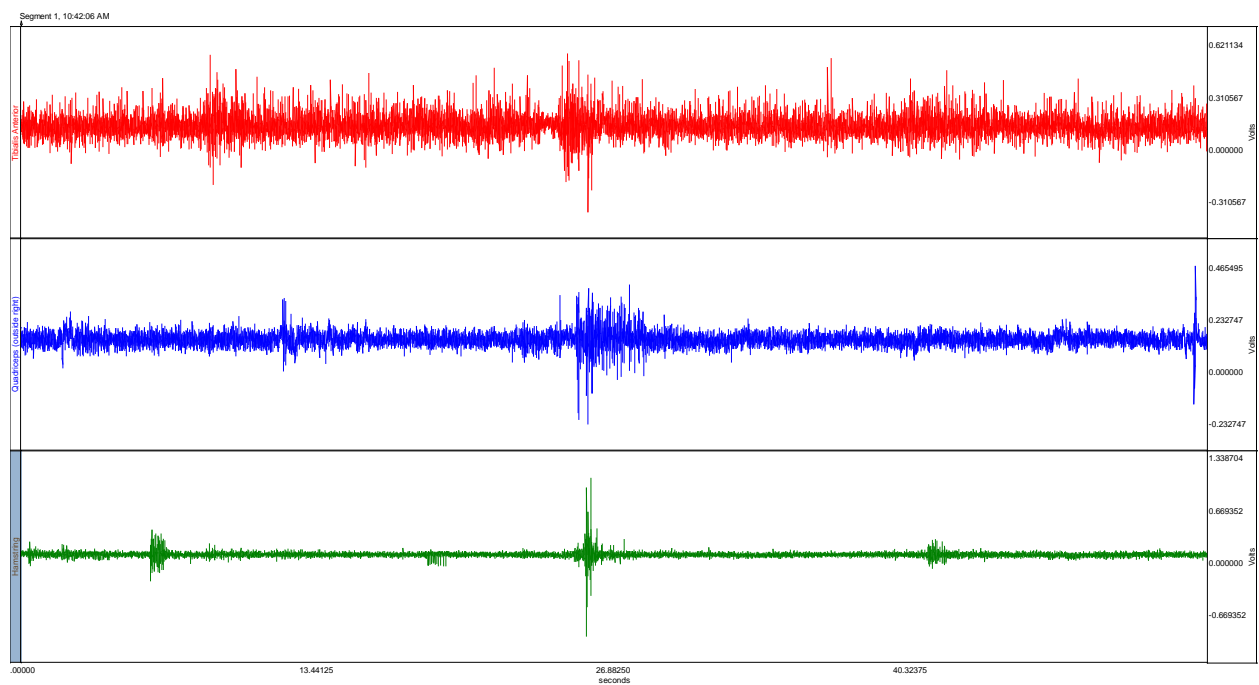


Figure 54: Lift ride – normal position, foot on bar, 60 seconds

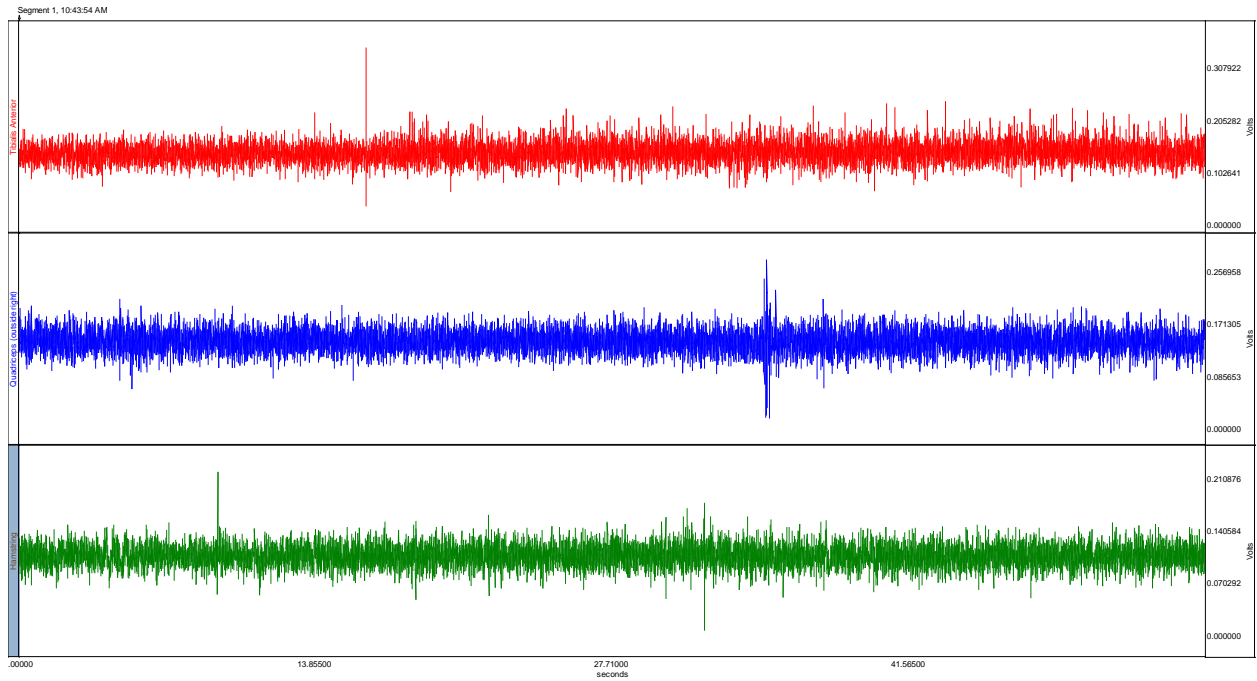


Figure 55: Lift ride – new position, foot on bar, 60 seconds

11.4.2. *Table of Values from EMG testing*

Table 7: Values from EMG testing

Voltage (V)	Control Group (Standing)	Skating - Normal Position	Skating - New Position		
Quadriceps Mean	0.170552	0.15169	0.14426		
Quadriceps Standard Deviation		1.21748	0.99266		
Quadriceps P-P		7.44781	6.65222		
Tibialis Anterior Mean	0.129713	0.14209	0.14095		
Tibialis Anterior Standard Deviation		1.31008	0.77875		
Tibialis Anterior P-P		8.7851	4.06738		
Hamstring Mean	0.128834	0.14566	0.10968		
Hamstring Standard Deviation		1.19158	0.38077		
Hamstring P-P		6.48804	2.5674		
Voltage (V)	Lift, Normal Position, no hold, 60s	Lift, Normal Position, hold, 60s	Lift, New Position, no hold, 60s	Lift, Normal Position, foot on bar, 60s	Lift, New Position, foot on bar, 60s
Quadriceps Mean	0.14439	0.14425	0.14436	0.14459	0.14257
Quadriceps Standard Deviation	0.03262	0.12167	0.02676	0.0305	0.01801
Quadriceps P-P	0.38849	0.92194	0.2652	0.31738	0.25696
Tibialis Anterior Mean	0.14002	0.13814	0.13908	0.14017	0.14086
Tibialis Anterior Standard Deviation	0.06443	0.10578	0.07449	0.06237	0.01918
Tibialis Anterior P-P	0.76904	0.97443	0.72723	0.7605	0.30792
Hamstring Mean	0.10878	0.11065	0.111	0.10505	0.10726
Hamstring Standard Deviation	0.03604	0.02785	0.05994	0.03569	0.01398
Hamstring P-P	0.42877	0.16876	0.56732	0.28534	0.21088

11.5. Material Property Tables



Aluminum, 6061, wrought, T6

Page 1 of 3

General properties

Designation

Al alloy: 6061-T6 (wrought)

UNS number	A96061		
Density	0.0965	- 0.0986	lb/in^3
Price	* 0.713	- 0.784	USD/lb

Composition overview

Composition (summary)

Al/1Mg/.6SiCuCr

Base	Al (Aluminum)		
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Composition detail

Al (aluminum)	97	- 99	%
Cr (chromium)	0	- 0.6	%
Cu (copper)	0	- 0.6	%
Mg (magnesium)	1		%
Si (silicon)	0	- 0.6	%

Mechanical properties

Young's modulus	9.86	- 10.7	10^6 psi	
Young's modulus with temperature	9.92	- 10.8	10^6 psi	
Parameters Temperature = 75.3°F				
Comp. Young's modulus with temperature	10.2	- 11.2	10^6 psi	
Parameters Temperature = 75.3°F				
Shear modulus	3.63	- 3.92	10^6 psi	
Bulk modulus	9.43	- 10.4	10^6 psi	
Poisson's ratio	0.325	- 0.335		
Shape factor	27			
Yield strength (elastic limit)	28	- 42.1	ksi	
Yield strength with temperature	27.9	- 41.9	ksi	
Parameters Temperature = 75.3°F				
Tensile strength	35	- 46.4	ksi	
Tensile strength with temperature	34.8	- 46.2	ksi	
Parameters Temperature = 75.3°F				
Compressive strength	30	- 42.1	ksi	
Flexural strength (modulus of rupture)	28	- 42.1	ksi	
Elongation	12	- 17	%	
Hardness - Vickers	95	- 105	HV	
Hardness - Brinell	13.8	- 15.2	ksi	
Fatigue strength at 10^7 cycles	13.1	- 14.5	ksi	
Fatigue strength model (stress range)	8.05	- 12.7	ksi	
Parameters Stress Ratio = 0, Number of Cycles = 1e7				
Fracture toughness	* 30	- 31.9	ksi.in^1/2	
Mechanical loss coefficient (tan delta)	* 1e-4	- 0.002		

Thermal properties

Melting point	1.08e3	- 1.2e3	°F
Maximum service temperature	230	- 338	°F
Minimum service temperature	-459		°F
Thermal conductivity	88	- 97.6	BTU.ft/h.ft^2.F
Specific heat capacity	0.21	- 0.218	BTU/lb.F
Thermal expansion coefficient	12.6	- 13.3	µstrain/°F
Latent heat of fusion	165	- 169	BTU/lb

No warranty is given for the accuracy of this data. Values marked * are estimates.

Electrical properties

Electrical resistivity 3.9 - 4.1 $\mu\text{ohm} \cdot \text{cm}$

Optical properties

Transparency Opaque

Durability: flammability

Flammability Non-flammable

Durability: fluids and sunlight

Water (fresh)	Excellent
Water (salt)	Acceptable
Weak acids	Excellent
Strong acids	Excellent
Weak alkalis	Acceptable
Strong alkalis	Unacceptable
Organic solvents	Excellent
UV radiation (sunlight)	Excellent
Oxidation at 500C	Unacceptable

Primary material production: energy, CO2 and water

Embodied energy, primary production	2.13e4	-	2.36e4	kcal/lb
CO2 footprint, primary production	11.4	-	12.6	lb/lb
Water usage	1.37e4	-	4.12e4	in ³ /lb

Material processing: energy

Casting energy	* 258	-	285	kcal/lb
Forging, rolling energy	* 324	-	358	kcal/lb
Metal powder forming energy	* 859	-	950	kcal/lb
Vaporization energy	* 1.81e3	-	2e3	kcal/lb
Conventional machining energy (per unit wt removed)	* 575	-	636	kcal/lb
Non-conventional machining energy (per unit wt removed)	* 3.39e3	-	3.75e3	kcal/lb

Material processing: CO2 footprint

Casting CO2	* 0.143	-	0.158	lb/lb
Forging, rolling CO2	* 0.239	-	0.264	lb/lb
Metal powder forming CO2	* 0.634	-	0.702	lb/lb
Vaporization CO2	* 1.34	-	1.48	lb/lb
Conventional machining CO2 (per unit wt removed)	* 0.425	-	0.47	lb/lb
Non-conventional machining CO2 (per unit wt removed)	* 2.5	-	2.77	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	1.85e3	-	2.2e3	kcal/lb
CO2 footprint, recycling	0.958	-	1.21	lb/lb
Recycle fraction in current supply	40.5	-	44.7	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
A renewable resource?	✗			

Notes

Typical uses

No warranty is given for the accuracy of this data. Values marked * are estimates.

Transportation equipment, heavy duty structures, marine uses, pipe, furniture, bridges, rail, towers, pylons.

Other notes

Immediate strength extrusion alloy. Prices of Aluminum alloys fluctuate greatly and are dependent on batch size, unit size, forming methods, etc.

Reference sources

Data compiled from multiple sources. See links to the References table.

MMPDS material? 

Standards with similar compositions

The following information is taken from ASM AlloyFinder 3 - see link to References table for further information.

CSA HA.4 0.6061 (ON Canada)
CSA HA.5 0.6061 (ON Canada)
CSA HA.6 0.6061 (ON Canada)
CSA HA.7 0.6061 (ON Canada)
CSA HA.7.1 0.6061 (ON Canada)
CSA HA.8 0.6061 (ON Canada)
ISO: Al-Mg1SiCu
UK (BS Pre-1980): H20
USA (UNS): A96061
Germany (W-Nr): 3.3211
Germany (DIN): AlMgSi1Cu
France: A-GSUC
Italy (UNI): 9006/2

Links

[MMPDS-03 Data](#)

[ProcessUniverse](#)

[Producers](#)

[Reference](#)

[Shape](#)

No warranty is given for the accuracy of this data. Values marked * are estimates.

Description

The material

POM was first marketed by DuPont in 1959 as Delrin. It is similar to nylon but is stiffer, and has better fatigue and water resistance - nylons, however, have better impact and abrasion resistance. It is rarely used without modifications: most often filled with glass fiber, flame retardant additives or blended with PTFE or PU. The last, POM/PU blend, has good toughness. POM is used where requirements for good moldability, fatigue resistance and stiffness justify its high price relative to mass polymers, like polyethylene, which are polymerized from cheaper raw materials using lower energy input.

Composition (summary)

(CH₂-O)_n

Image



General properties

Density	86.8	-	89.3	lb/ft ³
Price	1.51	-	1.72	USD/lb

Mechanical properties

Young's modulus	0.363	-	0.725	10 ⁶ psi
Shear modulus	0.122	-	0.33	10 ⁶ psi
Bulk modulus	0.638	-	0.667	10 ⁶ psi
Poisson's ratio	0.33	-	0.407	
Yield strength (elastic limit)	7.05	-	10.5	ksi
Tensile strength	8.7	-	13	ksi
Compressive strength	10.9	-	18	ksi
Elongation	10	-	75	%
Hardness - Vickers	14.6	-	24.8	HV
Fatigue strength at 10 ⁷ cycles	* 3.18	-	4.97	ksi
Fracture toughness	1.55	-	3.82	ksi.in ^{1/2}
Mechanical loss coefficient (tan delta)	* 0.00638	-	0.017	

Thermal properties

Melting point	320	-	363	°F
Glass temperature	-0.67	-	17.3	°F
Maximum service temperature	170	-	206	°F
Minimum service temperature	-190	-	-99.7	°F
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.128	-	0.203	BTU.ft/h.ft ² .F
Specific heat capacity	0.326	-	0.342	BTU/lb.F
Thermal expansion coefficient	42.1	-	112	µstrain/°F

No warranty is given for the accuracy of this data. Values marked * are estimates.

Electrical properties

Electrical conductor or insulator?	Good insulator		
Electrical resistivity	3.3e20	-	3e21 μohm.cm
Dielectric constant (relative permittivity)	3.6	-	4
Dissipation factor (dielectric loss tangent)	9.5e-4	-	0.005
Dielectric strength (dielectric breakdown)	384	-	521 V/mil

Optical properties

Transparency	Opaque
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Processability

Castability	1	-	2
Moldability	4	-	5
Machinability	3	-	4
Weldability	4	-	5

Eco properties

Embodied energy, primary production	* 1.08e4	-	1.19e4 kcal/lb
CO2 footprint, primary production	* 3.8	-	4.2 lb/lb
Recycle	✓		
Recycle mark			



Supporting information

Design guidelines

POM is easy to mold by blow molding, injection molding or sheet molding, but shrinkage on cooling limits the minimum recommended wall thickness for injection molding to 0.1mm. As manufactured, POM is gray but it can be colored. It can be extruded to produce shapes of constant cross section such as fibers and pipes. The high crystallinity leads to increased shrinkage upon cooling. It must be processed in the temperature range 190-230 °C and may require drying before forming because it is hygroscopic. Joining can be done using ultrasonic welding, but POM's low coefficient of friction requires welding methods that use high energy and long ultrasonic exposure; adhesive bonding is an alternative. POM is a good electrical insulator. Without coPolymerization or the addition of blocking groups, POM degrades easily.

Technical notes

The repeating unit of POM is $-(CH_2O)_n$ and the resulting molecule is linear and highly crystalline. Consequently, POM is easily moldable, has good fatigue resistance and stiffness, and is water resistant. In its pure form, POM degrades easily by dePolymerization from the ends of the polymer chain by a process called 'unzipping'. The addition of 'blocking groups' at the ends of the polymer chains or coPolymerization with cyclic ethers such as ethylene oxide prevents unzipping and hence degradation.

Typical uses

POM is more expensive than commodity polymers such as PE, so is limited to high performance applications in which its natural lubricity is exploited. It is found in fuel-system; seat-belt components; steering columns; window-support brackets and handles; shower heads, ballcocks, faucet cartridges, and various fittings; quality toys; garden sprayers; stereo cassette parts; butane lighter bodies; zippers; telephone components; couplings; pump impellers; conveyor plates; gears; sprockets; springs; gears; cams; bushings; clips; lugs; door handles; window cranks; housings; seat-belt components; watch gears; conveyor links; aerosols; mechanical pen and pencil parts; milk pumps; coffee spigots; filter housings; food conveyors; cams; gears; TV tuner arms; automotive underhood components.

Tradenames

Acetron, Delrin, Fulton, Latan, Lupital, Plaslube, Tenac, Thermocomp, Ultraform

No warranty is given for the accuracy of this data. Values marked * are estimates.

Links

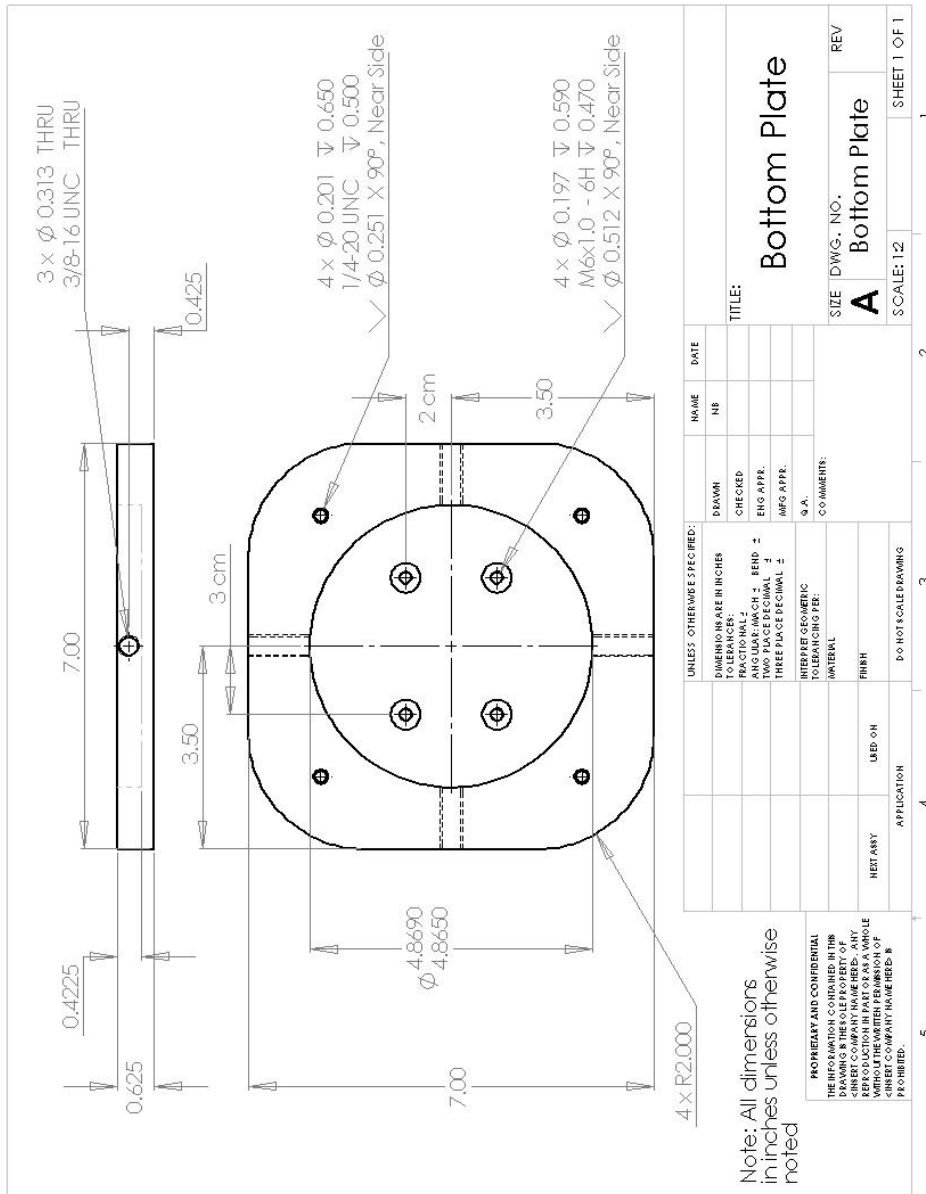
Reference

ProcessUniverse

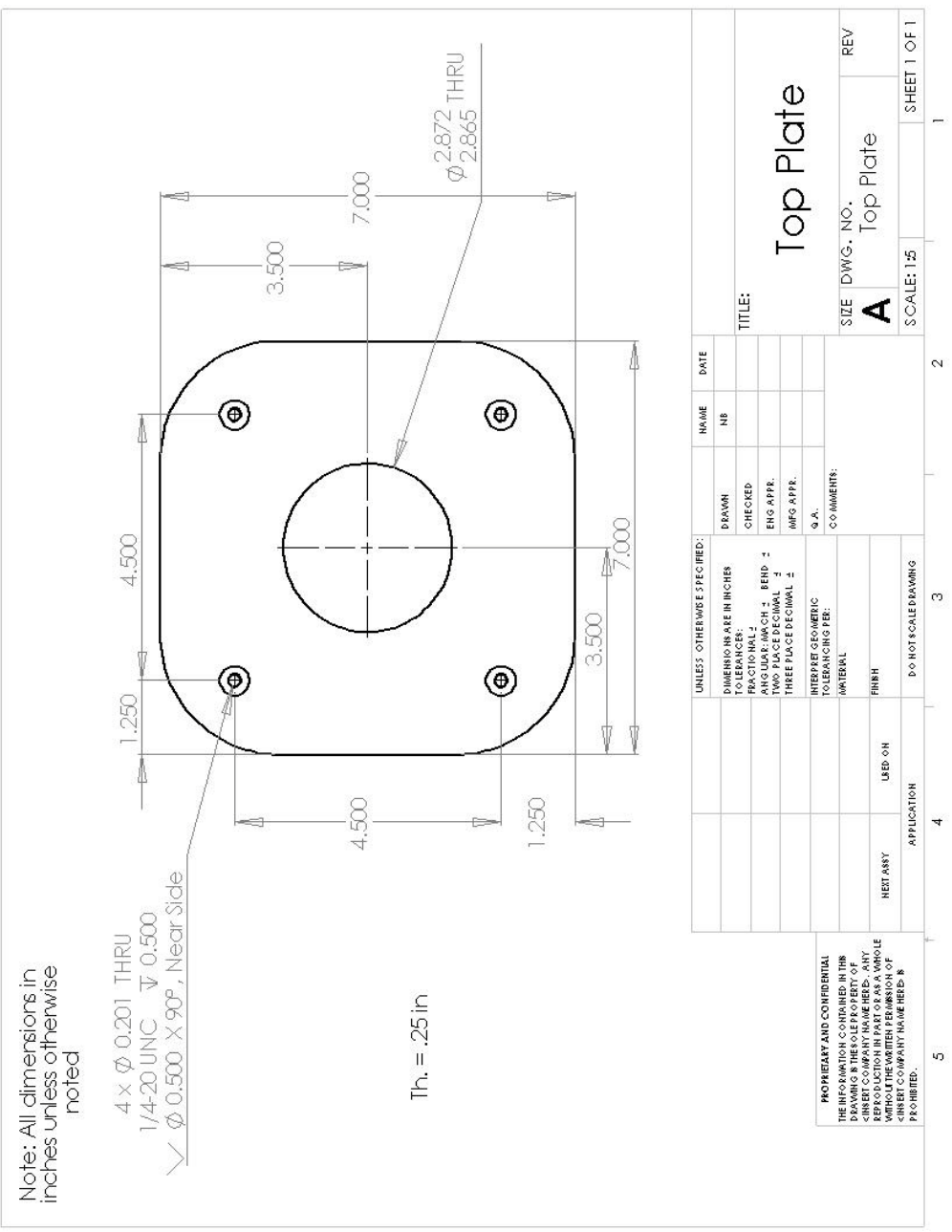
Producers

No warranty is given for the accuracy of this data. Values marked * are estimates.

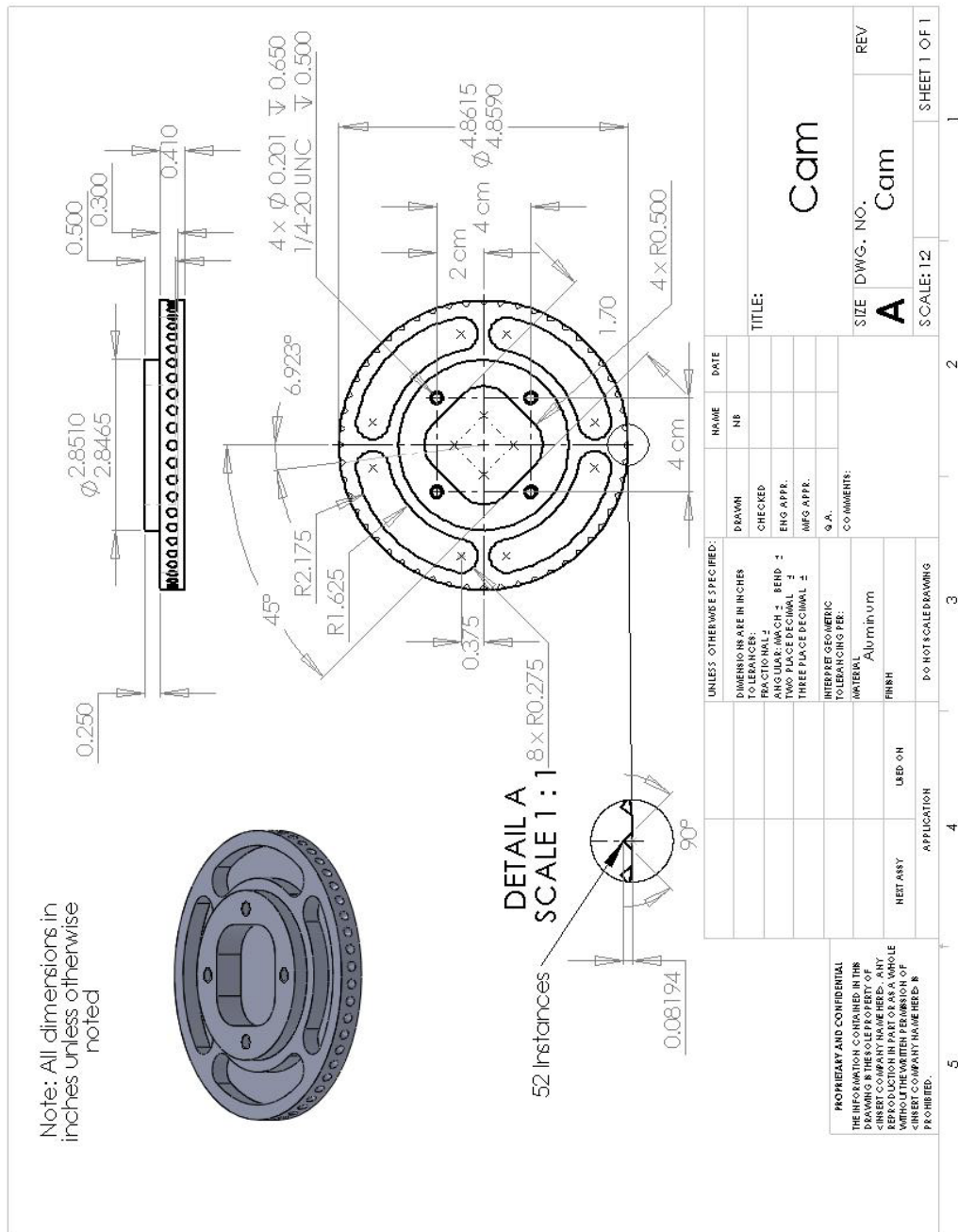
11.6.1. Bottom Plate



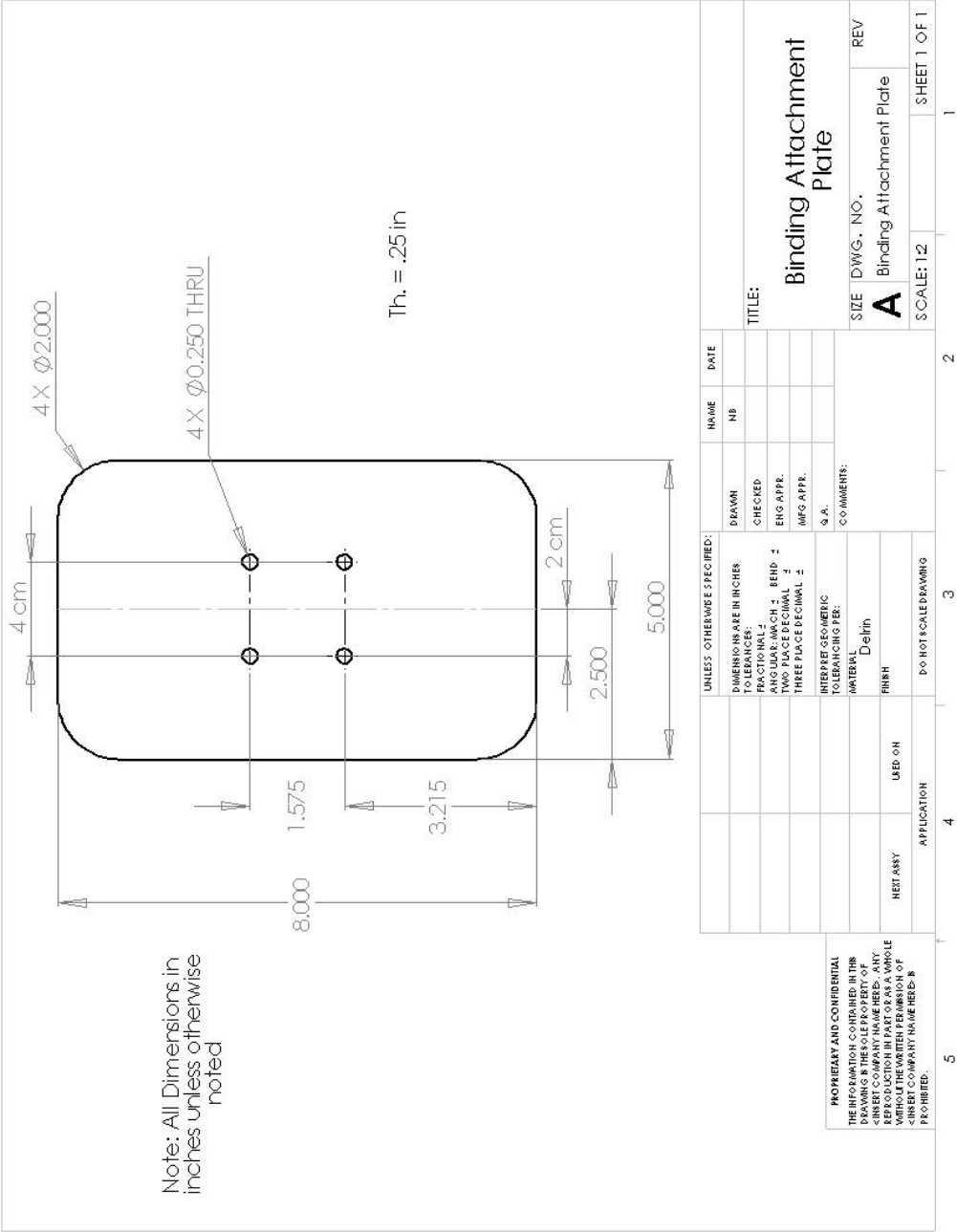
11.6.2. Top Plate



11.6.3. Cam



11.6.4. Binding Attachment Plate



11.7. Exploded View of Design with Labeled DPs

[FR] Functional Requirements		[DP] Design Parameters	
0	FR Provide an interface between the binding and board which allows	DP	Adjustable rotating binding interface
1	FR Transfer all loads except for rotational from binding to board	DP	Load Transfer system
1.1	FR Transfer loads from Foot to Binding	DP	Binding Straps
1.2	FR Transfer loads from binding to binding attachment plate	DP	Binding attachment plate that is flat against the binding and four mounting bolts 4cm apart in a square pattern
1.3	FR Transfer loads from binding to cam	DP	Four mounting bolts 4cm apart in a square pattern that attach from the binding to the cam
1.4	FR Transfer loads from cam to the top plate.	DP	A circular hole in the top plate to the bottom plate with a diameter of 2.85in.
1.5	FR Transfer loads from the top plate to the bottom plate.	DP	Four mounting bolts 4.5in apart in a square pattern along the top plate and the base plate.
1.6	FR Transfer loads from base to snowboard surface.	DP	Bottom plate is flat against the snowboard surface and four mounting bolts 4cm apart in a square pattern
2	FR Control Rotation	DP	Cam with a ball plunger system
2.1	FR Prevent rotation at low torques (below $T=15Nm$)	DP	Ball Plunger positioning in conical detents.
2.2	FR Allow rotation at high torques (above $T=15Nm$)	DP	Ball plunger and angle of the conical detent . (45 Degrees)
2.3	FR Allow many different angles of adjustment (13)	DP	Multiple conical detents along the outer surface of the CAM. (6.93 degrees apart)
3	FR Prevent Environmental Damage	DP	Top plate and binding attachment plate seal the system from environmental problems.
4	FR Allow Stance Adjustability for any snowboard	DP	Use currently practiced methods and apply it.
4.1	FR Allow placement adjustability	DP	Four mounting holes 4cm apart in a square pattern to allow the binding to be configured for all foot widths
4.2	FR Allow the binding angle to be adjustable	DP	Top plate acts as the snowboard surface.

Figure 57: FRs and DPs

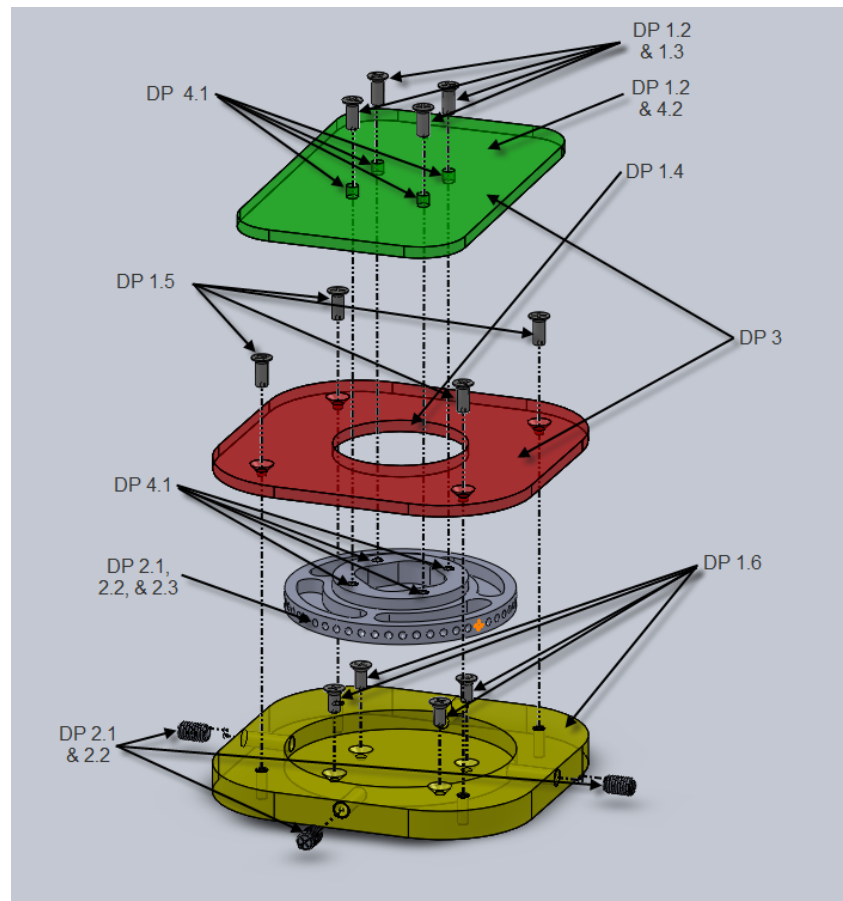


Figure 56: Exploded Model View with DPs